Volume 33 JANUARY, 1949 Number 1

BULLETIN
of the
American Association *of* Petroleum Geologists

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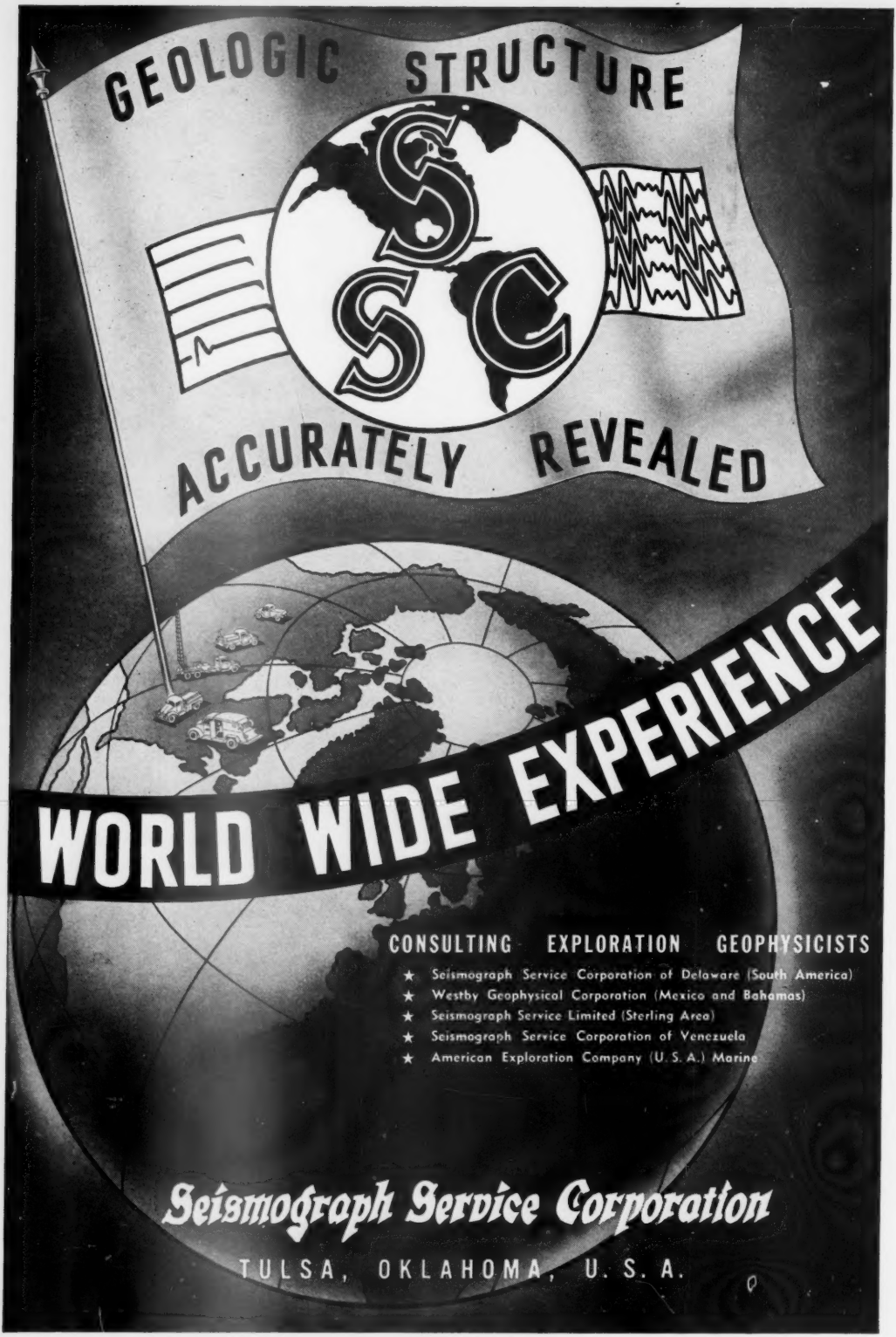
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of the

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THE BULLETIN is published by the Association on the 15th of each month.

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BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

SUBSCRIPTION PRICE to non-members is $15 per year (separate numbers, $1.50), prepaid to addresses in the United States; outside the United States, $15.40.

CLAIMS FOR NON-RECEIPT must be sent within 3 months of date of publication, to be filled gratis.

BACK NUMBERS, if available, may be ordered from Headquarters. Price list on request.

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Cloth-bound Bulletin, Vols. 13 (1929)-15 (1931) incl., each	$5.00	$6.00

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Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1913.

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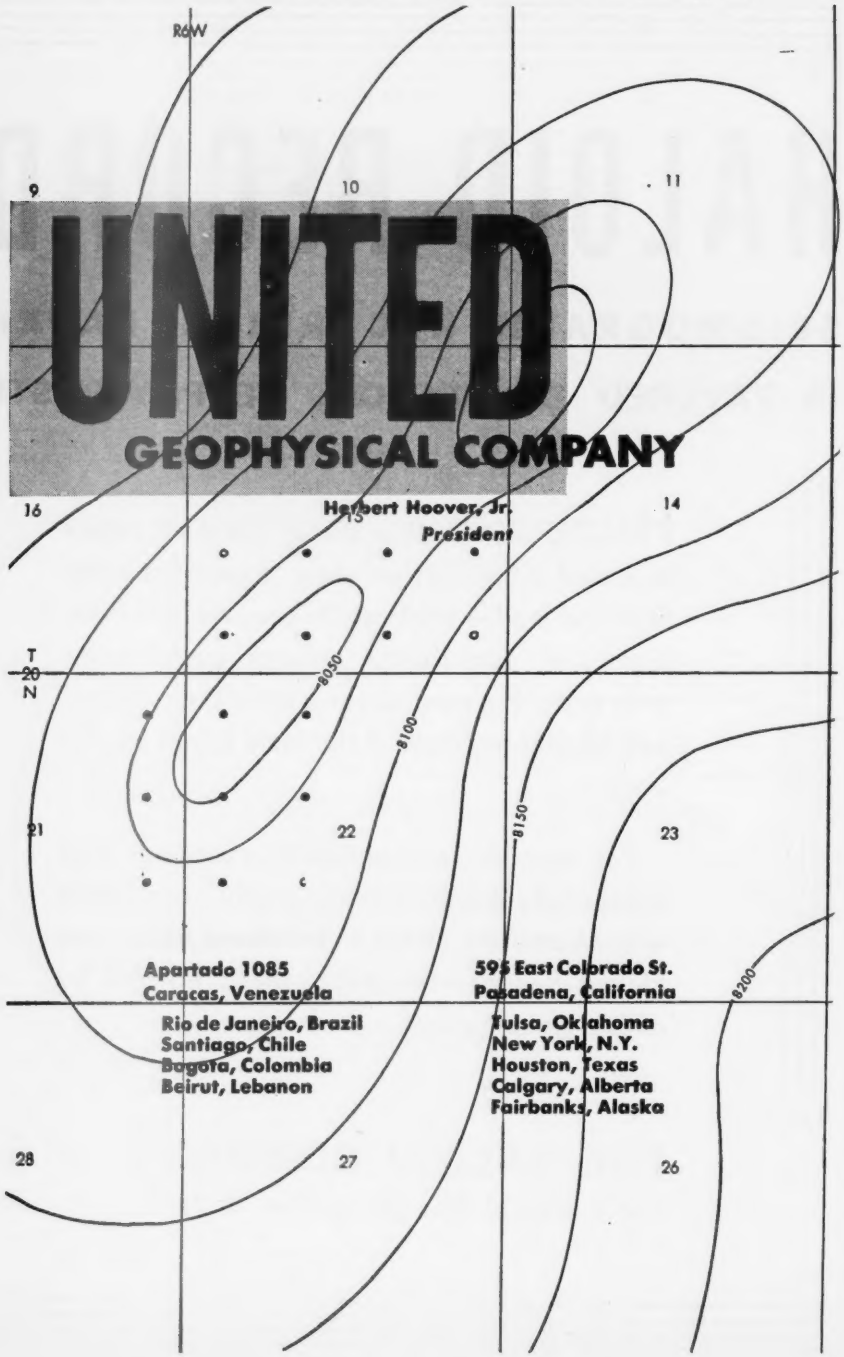

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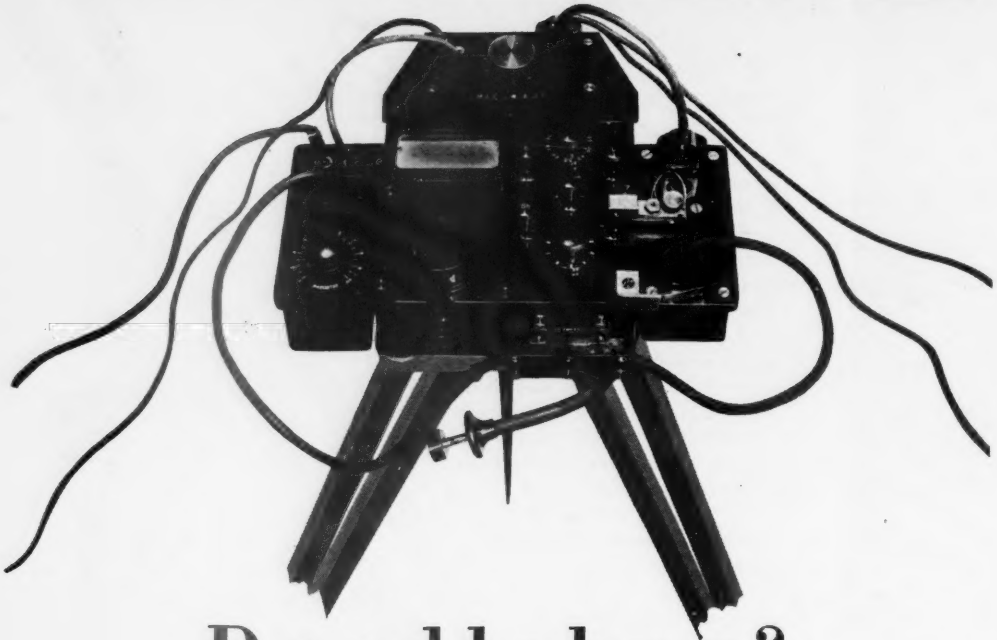

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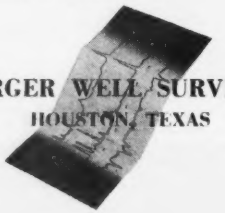

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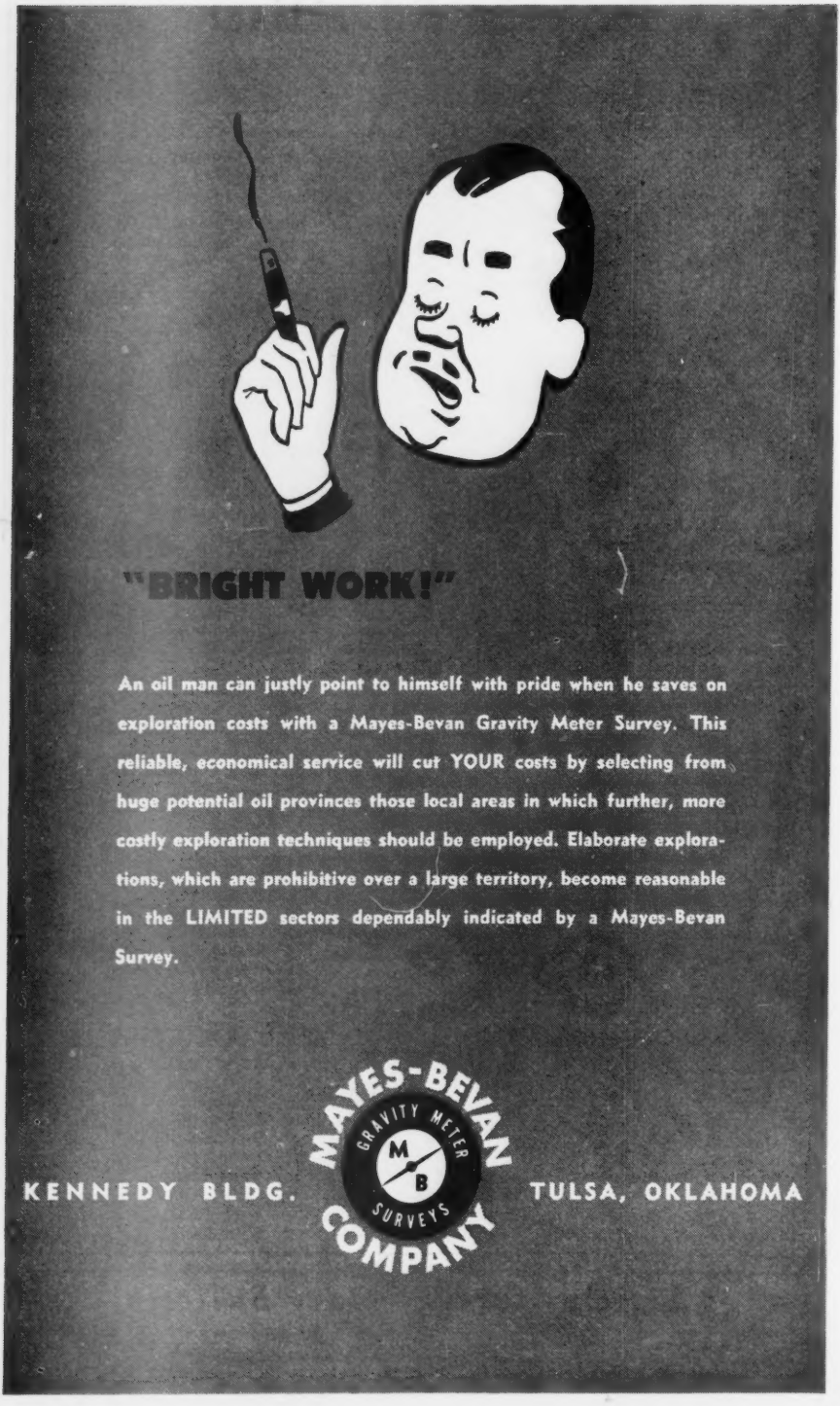
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Volume 33 Number 1

BULLETIN
of the
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

JANUARY, 1949

DIGBOI OIL FIELD, ASSAM[1]

E. V. CORPS[2]
Digboi, Assam

ABSTRACT

The Digboi oil field is in northeastern Assam on a faulted elongate anticline in rocks of the Tipam series (middle Miocene). The three main producing formations are the Bappapung sandstone, the Nahor oil sand, and the members of the Digboi oil sand group. There is pronounced lateral variation, and permeabilities are very low. As a result, productivity is very variable and it has been necessary to use very close spacing. The oil is remarkable for its high pour point, 95° F., and high wax content. Brief reference is made to several problems, including the difficulty of differentiating oil, gas, and water-bearing sands in electrical surveys because of the low salinity of the formation waters, paraffination, loss of circulation while drilling, and migration of oil into the structure from the Barail (Eocene-Oligocene) beds below.

INTRODUCTION

The Digboi oil field is almost at the head of the Assam Valley nearly 600 miles northeast of Calcutta. Although Digboi is on the edge of the valley, through which flows the Brahmaputra River, and is only 500 feet above sea-level, it is surrounded by a semi-circle of high mountain ranges (Fig. 1). On the north is the eastern continuation of the Himalayan Range, whose great snow-covered peaks, rising to 25,000 feet, can easily be seen in clear weather. On the east are the 15,000 foot peaks which mark the boundary between India and China; these are "The Hump" over which the Air Transport Command ferried vast quantities of supplies into China. On the southeast is the Patkai Range, rising to 8,000 feet. It was over this range that the first stage of the great 1,000-mile Ledo Road was built during World War II from Assam to China. This road begins at the village of Ledo, which is 12 miles southeast of Digboi; it is now known as the Stilwell Road.

The climate is very wet; the annual rainfall is 120 inches, almost all of which falls in the period from April to October. Consequently, the region was, until a century ago, almost entirely covered by thick jungle. Since then, clearings for tea and rice cultivation have led to the opening of much of the flat ground of the valley, but the foothills and the lower slopes of the mountains remain covered by

[1] Manuscript received, July 30, 1948. Published by permission of The Burmah Oil Company, Ltd.

[2] Geologist, Burmah Oil Company, Ltd.

dense sub-tropical jungle. Assam is a very malarious province but in the oil field area malarial control has greatly reduced and is still reducing the occurrence of the disease.

The Digboi oil field is not large, but it was important during World War II. It was the most easterly Allied oil field in operation during the entire Japanese campaign. Located in the forward area during the period 1942–1944, it was for some time only 75 miles from the Japanese headquarters at Shingbwiyang. Throughout this time drilling activity was intensified, and production was maintained much above the peace-time level. In the early part of this war period, before arrangements were completed for the importation and piping to the Assam air fields of gasoline from other sources, it was on this Digboi production that the Army and Air Forces based on Upper Assam relied chiefly for their gasoline.

GEOLOGY OF UPPER ASSAM

The geology of Assam has been described in detail elsewhere,[3] and is presented only briefly here.

Stratigraphy.—Except for the Central Assam Range and the Eastern Himalayas almost all of Assam consists of Tertiary rocks or of Recent alluvial deposits. The more important local divisions of the succession in Upper Assam and their approximate ages are given in Table I.

The Disang series includes a great thickness, possibly more than 10,000 feet, of shales with subordinate sandstones. The Barail series is more arenaceous and contains thick seams of coal and many oil showings. It is separated by an important unconformity from the overlying Miocene beds. The Surma series is poorly developed in Upper Assam and is entirely missing from some sections, where the Barail series is directly overlain by the Tipam series. The Surma series consists of alternating beds of shale, sandy shale, shaly sandstone, sandstone, and conglomerate. In Upper Assam it is less than 2,000 feet thick, although farther southwest it attains a thickness exceeding 20,000 feet. The Tipam series includes sandstones that are somewhat coarser, mottled clays, and a few conglomerates. In this series there is believed to be an unconformity which may be correlated with a break that has been more fully investigated in the southern part of Assam; if so, the upper part of the Tipam series of Upper Assam should be separated as a different series. Another break occurred after the deposition of the Tipam beds, which are consequently unconformably overlain by the next group, the Dihing series, largely pebble beds. Alluvial deposits cover a great area and include various types of high-level alluvium, in addition to the sand, silt, and clay, which make up the flat ground through which the Brahmaputra River flows.

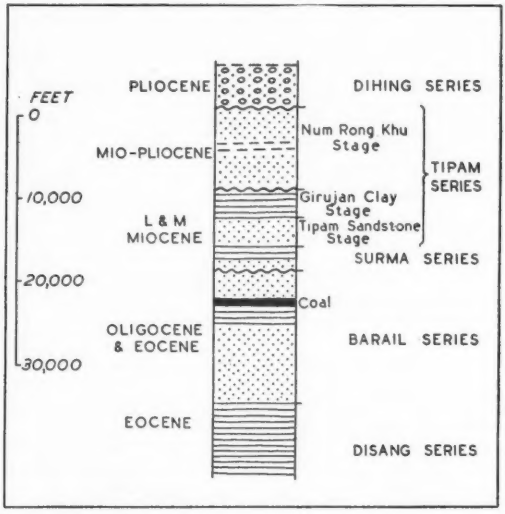
The rocks of Assam are remarkable for the paucity of fossils and consequently

[3] H. M. Sale and P. Evans, "The Geology of British Oil Fields; I, The Geology of the Assam-Arakan Oil Region (India and Burma)," *Geol. Mag.*, Vol. 77, No. 5 (1940). P. Evans, "The Tertiary Succession in Assam," *Trans. Min. Geol. Inst. India*, Vol. 27, 3 (1932).

there is difficulty in assigning the different divisions to their correct places in the European time-scale. Correlation in the province has been greatly helped by heavy-mineral investigations.[4]

TABLE I

STRATIGRAPHIC SUCCESSION, UPPER ASSAM



Structure.—The Central Assam Range is geologically the northeastern continuation of the Indian Peninsula, and although the ancient metamorphic rocks of these hills are covered with alluvium near Jorhat, it is probable that similar rocks extend for a considerable distance northeastward, buried at great depth by Tertiary deposits and the alluvium of the Brahmaputra River. These old rocks are overlain by a shore-line development of the higher groups of the Tertiary and have been overridden both from the northwest and the southeast by a series of overthrust strips of Tertiary and (in the northwest) older rocks. The geology of the southeastern side of the Assam Valley (Fig. 2) has been examined in detail and many thrust faults have been accurately traced. The most important of these is the Naga thrust which for many miles closely follows the southeastern edge of the Brahmaputra alluvial valley. Associated with the thrust faults there are a few areas in which anticlinal structure still remains; of these, Digboi is one. However, most of the hills southeast of the valley consist of slices of Tertiary

[4] R. J. Hayman, "A New Form of Range Table for the Graphical Representation of Heavy Mineral Analyses," *Quar. Jour. Geol. Min. Met. Soc. India*, Vol. 18 (1), pp. 5–12.

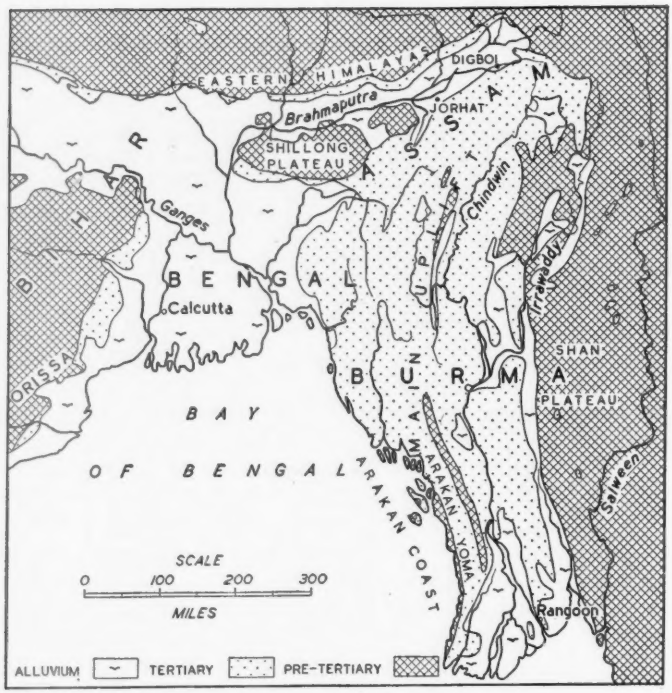


FIG. 1.—Index map showing location of Digboi.

rocks pushed one over the other. It is probable that in the early stages of earth movement there were many anticlines and synclines with a general northeast-southwest strike, and that as the earth movements proceeded the anticlines first

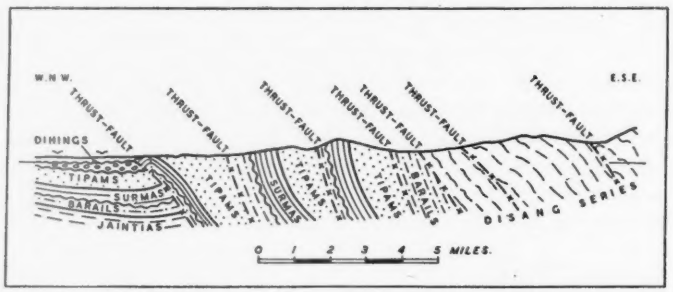


FIG. 2.—Section southeast of Assam Valley.

became asymmetrical and then yielded along the steep flanks, denudation subsequently removing all traces of anticlinal structure from the greater part of the area.

GEOLOGY OF DIGBOI

Position.—The Digboi oil field is on a long, narrow, faulted anticline in which a large part of the Tipam series is exposed (Fig. 3). The fault which bounds the structure on the north is the Naga thrust, and Digboi is a local culmination at the northeastern end of a long line of uplift known as the Jaipur anticline.

Stratigraphy.—The detailed stratigraphic succession found in the Digboi field is given in Table II. The greater part of the area occupied by wells is on the out-

TABLE II

STRATIGRAPHIC SUCCESSION, DIGBOI FIELD

		Alluvium	0–300 feet
		UNCONFORMITY	
		Charali Beds (? Older alluvium)	up to 700
		UNCONFORMITY	
DIHING SERIES		Dhekiajuli Beds	up to 6,000
		UNCONFORMITY	
TIPAM SERIES	Girujan Clay Stage	Girujan Clay (G.C.)	over 5,800
		Arenaceous Alternations (A.A.)	500
	Tipam Sandstone Stage	Hansapung Sandstone (H.P.S.)	900
		Bappapung Clay (B.P.C.)	300
		Bappapung Sandstone (B.P.S.)	600
		Upper Digboi Mottled Clay (U.D.M.C.)	250
		Nahor Oilsand (Nhr)	250
		Lower Mottled Clay (L.M.C.)	250
		Upper Digboi Oilsand Group (D.O.G.(U))	250
		Middle Digboi Oilsand Group (D.O.G.(M))	620
		Basal Digboi Oilsand Group (D.O.G.(B))	200
SURMA SERIES			0–200
		UNCONFORMITY	
BARAIL SERIES		? Upper Tikak Parbat Stage	0–200

crop of the lower division of the Tipam series, the Tipam sandstone stage. Beds of this stage down to the lower Mottled clay are exposed in the Digboi fold itself but lower beds crop out in parts of the Jaipur anticline on the southwest. On the northern flank of the Digboi fold, exposures are limited but Girujan clays and the uppermost Tipam sandstones crop out.

There are no exposures north of the Naga thrust, the country being entirely alluvial. However, wells which have penetrated below the thrust have proved the presence of a thick group of coarse sands, with a few pebble beds, known as the Dhekiajuli beds and referred to the Dihing series. These have also been found at shallow depths in core holes drilled to locate the sub-alluvial position of the

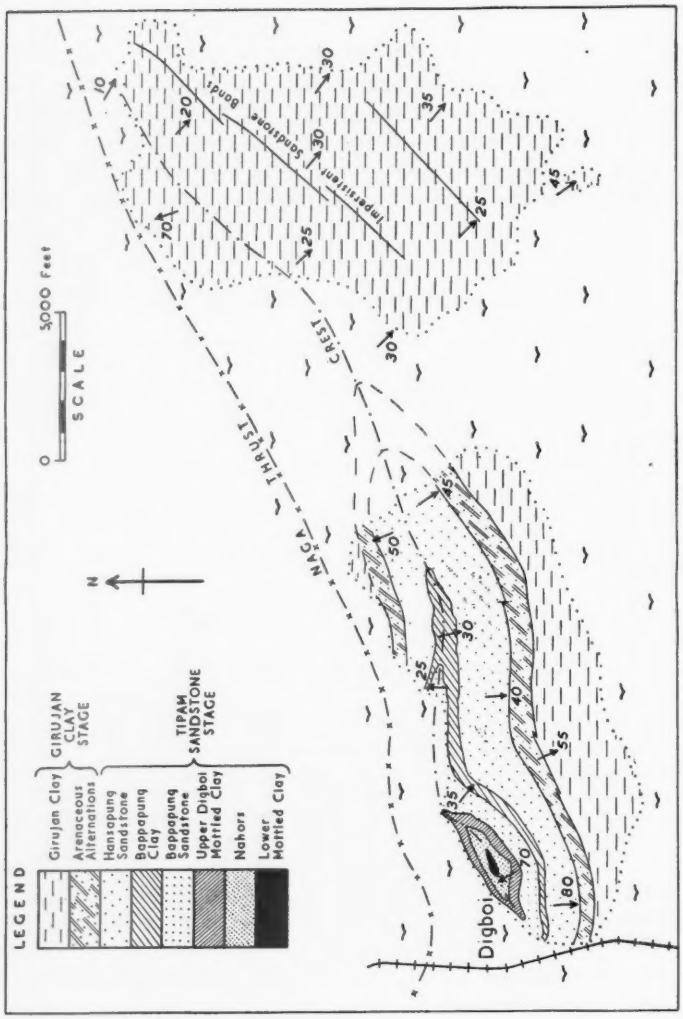


FIG. 3.—Geological map of Digboi field.

Naga thrust. However, some of these core holes have found a variable thickness of another group of coarse- to medium-grained sands, known as the Charali beds. The exact relationship of these beds is not yet clear, and they may be representative of some older alluvium.

A small thickness, not more than 200 feet, of beds referable to the Surma series though in many respects unrecognizable from the overlying basal Digboi oil sand group, is found in the eastern part of the field. Elsewhere, except for one doubtful occurrence, the Surma is absent, and Tipam sandstones rest directly on beds of upper Barail age. The probable importance of this contact in regard to the migration of oil into the Digboi structure is mentioned later. The lowest beds encountered in drilling belong to the Barail series, but little more than 200 feet of this series has been found, lower beds being cut out by the Naga thrust. Although there is an important stratigraphic break, at the top of the Barail, there is no angular unconformity, and the dip in the Barail is the same as that of the overlying beds.

The greater part of the nomenclature dates from 25 years ago and is still in general use, but is now supplemented by more precise divisions based on Schlumberger surveys. Arenaceous divisions are referred to as S.1, S.2, *et cetera;* clays as C.1, C.2, *et cetera;* and argillaceous sands, sandy clays, and alternations of sand and clay as A.1, A.2, *et cetera*. The subdivisions of the Tipam sandstone stage (Table II) persists throughout the field but vary appreciably in thickness (Fig. 4). The sandstone and oil sand groups are not all arenaceous but are merely

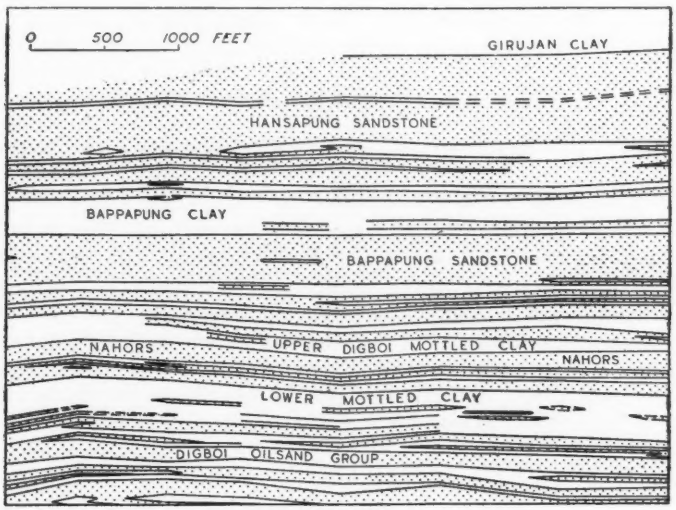


FIG. 4.—Longitudinal section of part of Digboi field.

ranges of strata with predominance of sand. Similarly the clay groups, although mainly argillaceous, contain lenticular beds of fine sandstone, clayey sandstone, coarse sandstone, and calcareous sandstone. Evidence from cores supplemented in recent years by the electrical logging of every well has enabled accurate sections to be drawn throughout the field and these show a remarkable development of lateral variation in all the formations drilled. This is in accordance with the observations made where the entire Tipam sandstone stage crops out in adjoining areas.

Structure.—The Digboi structure is very elongate, the anticline extending approximately west-southwest and east-northeast. It is very sharply folded and in parts markedly asymmetrical, the northern flank being the steeper flank. The

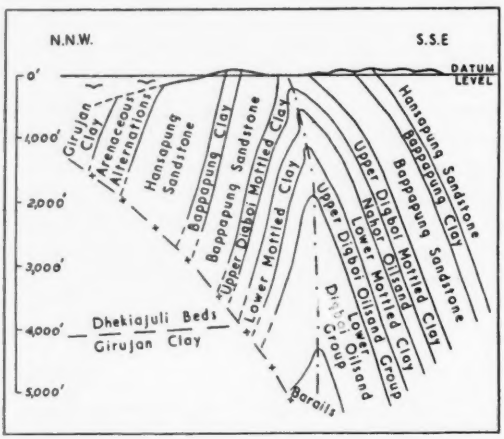


FIG. 5.—Section across western end of Digboi field.

southern flank disappears under the alluvium about a mile south of the crest. Much of the northern flank is covered by alluvium, but it is known to be cut off by the Naga thrust which is concealed by the alluvium and extends parallel with the fold on the north.

A section through the western end of the fold is shown in Figure 5. The structure is very pinched, and near the surface there is some overfolding on the north flank, perhaps accompanied by faulting. Figure 6 is a section east of the summit of the structure. It is characterized by marked asymmetry, the dip on the north flank increasing from 65° near the surface to vertical at depth; the dip on the south flank is approximately 45°. Figure 7 is a section at the eastern end of the productive area. The fold is asymmetrical but is much less pinched.

The structure is dominated by the south-hading Naga thrust. This thrust, or its equivalent, is known for a distance of more than 250 miles, but for most of this

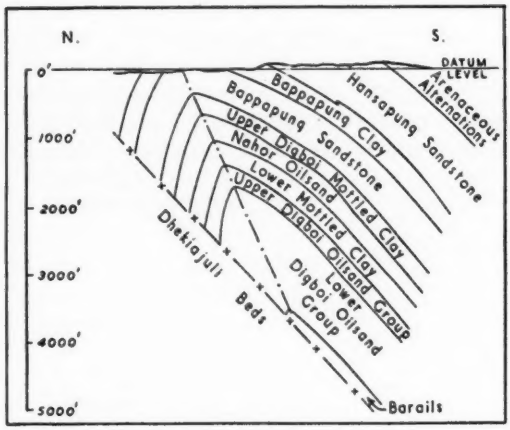


FIG. 6.—Section near central part of Digboi field.

distance it is beneath the alluvium, parallel with and north of the exposed rocks. The line of the sub-alluvial outcrop of the thrust has been determined in the vicinity of Digboi and nearly 100 miles southwest by torsion-balance observations, checked by a few shallow core holes. Many of the more recent wells have been drilled to the thrust and its position at depth is fairly accurately known for

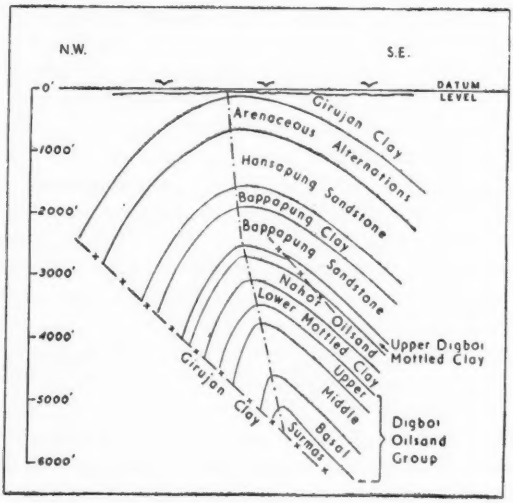


FIG. 7.—Section across eastern end of Digboi field.

a distance of 5 miles. At depth the thrust plane hades parallel with the beds of the south flank.

The surface summit of the structure is in the western part of the oil field (Fig. 8). From this culmination there is strong westerly pitch reaching a maximum of 70° within ½ mile of the summit. There is a general easterly pitch of 10°, but important local variations occur, some as a result of changes in the nature of

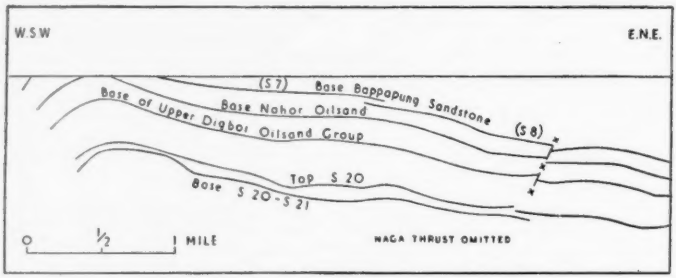


FIG. 8.—Crestal section through Digboi field.

the folding and some because of stratigraphic variations. These give rise to domes and saddles underground. At the eastern end, the structure is thought to run into the Naga thrust.

OIL POOLS OF DIGBOI FIELD

Productive ranges.—The Hansapung sandstone yields large quantities of fresh water, but in the extreme eastern part of the oil field a few beds show oil, but do not produce. The Bappapung sandstone also yields fresh water in the western part of the structure, but on the eastern pitch there are oil sands which have recently been developed and now yield 6 per cent of the production of the Digboi field. The Nahor oil sand and the underlying beds also produce in nearly the same proportion but were formerly more important. The Digboi oil sand group, divided into upper, middle, and basal sub-groups by two persistent clay bands, yields the greatest part of the oil. The thin Surma series has recently been found to contain oil in the eastern part of the field. The Barail sands have been found to contain only feeble showings of waxy, inspissated oil, and have shown no oil when tested.

Development.—As early as 1867, shallow wells were drilled in Upper Assam near the larger seepages, but these were not at Digboi, where drilling did not begin until 1889. The first group to be developed was the Nahor oil sand, whose strongly oil-stained and paraffined outcrop attracted the attention of the early operators. Later, the more productive oil sands of the Digboi oil sand group were discovered. The small productive pools of the Bappapung sandstone down the

easterly pitch are of comparatively recent development, though production in this group had been proved more than 30 years ago.

The Bappapung sandstone, the Nahor oil sand, and the Digboi oil sand groups have been developed by separate generations of wells. Each of these groups consists of several individual oil-bearing sands, and the oil is found in chance permeable streaks and lenses scattered irregularly throughout these sands.

Taking the Bappapung sandstone and associated beds as an example, five main oil-bearing sands are recognized. On the Schlumberger log, they are known as follows.

S.6
S.7
S.8—substage (a)
S.8—substage (b)
A.3—a sandstone in the U.D.M.C. but developed with the B.P.S.

The productive area of the Bappapung sandstone consists of four narrow crestal segments about $\frac{1}{4}$ mile or less in width, distributed in a distance of 2 miles (Fig. 9). In these segments occur the following distinct pools, separated by barren or water-bearing areas.

S.6	2 pools
S.7	3 pools
S.8 (a)	4 pools
S.8 (b)	3 pools
A.3	3 pools

Similar conditions are found in the Nahor oil sand, of which a general outline of the productive area is shown in Figure 10. In the Digboi oil sand group there are 12 main productive sands, the pools in which overlap, so that the entire $4\frac{1}{2}$-

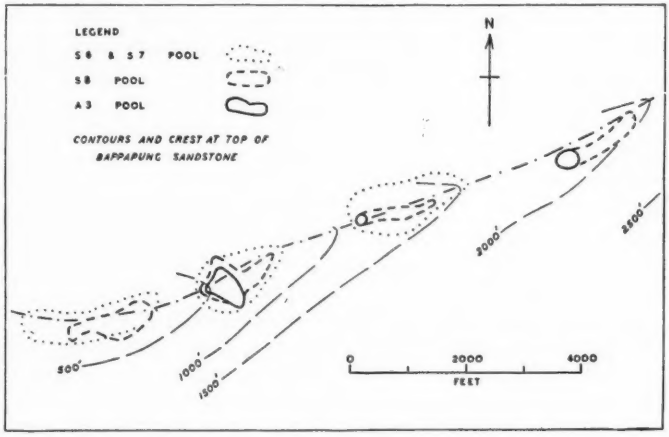


FIG. 9.—Oil pools of Bappapung sandstone group.

mile, narrow, tapering area shown in Figure 11 is productive in some parts of the group and there are no non-productive gaps as with the shallow groups.

It has been necessary, in order to develop the field remuneratively, to take the production of groups of sands together. However, this group production has

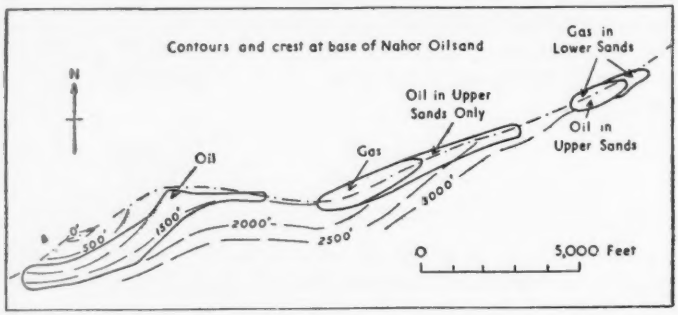


FIG. 10.—Oil pools of Nahor oil sand.

been restricted by the drilling of separate generations of wells to the Bappapung sandstone, Nahor oil sand, and Digboi oil sand group; and by the present policy of selective bullet-perforation it has been possible to limit still further the ranges from which production is taken within these groups.

Sand characteristics.—The porosities and permeabilities of the sand groups are summarized in Table III. The low permeabilities of the Digboi oil sand group are

TABLE III

POROSITIES AND PERMEABILITIES, DIGBOI FIELD

Sand Group	*Porosity (Percentage)*		*Permeability (Millidarcys)*	
	Range	*Average*	*Range*	*Average*
Bappapung sandstone	9–27	16	27–470	140
Nahor oil sand	3–20	10	7–270	90
D.O.G.(U)	9–18	12	7– 24	13
D.O.G.(M)	4–21	10	0.5– 80	18
D.O.G.(B)	4–19	11	0.3– 65	10
Surma sands	6–21	11	0.2–540 (Very variable)	110

noteworthy. It is thought that in some wells which have given a comparatively large initial production, the productivity of this group is dependent largely on the presence of highly permeable streaks, which have assumably escaped measurement, and on fissuring.

Spacing.—The pronounced lateral variation in the oil sands coupled with their generally low permeability has led to the development of the field at a close spacing. The intervals actually used are influenced by the depth necessary to drill,

and the deeper wells are spaced more widely than the shallow wells. In areas known to be much fissured, two or three pairs of wells have shown complete interference with one another; that is, either well will produce by itself the same volume of oil as is obtained when both wells are on production together. Apart

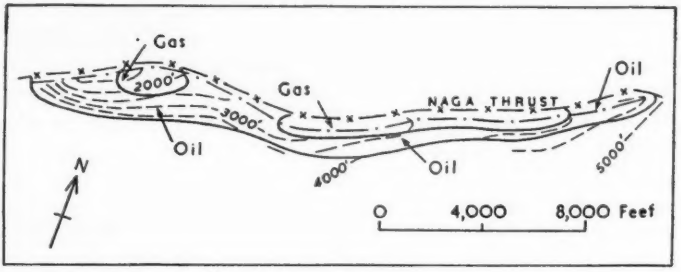


FIG. 11.—Oil pool of Digboi oil sand group.

from these rare and special cases, no significant interference has been detected in any of the sand groups, despite the close spacing adopted.

Pressures.—As is to be expected, the reservoir pressure varies considerably from place to place. The development of the Nahor oil sand and the Digboi oil sand groups was started long before bottom-hole pressure recorders were available and we can only guess at the original pressures in these sands. As an indication of the order of pressures in these main groups, and having regard to the limitations previously expressed, we may quote the following.

	Reservoir Pressure (p.s.i.)	
	Original	*Present*
Bappapung sandstone	700	150
Nahor oil sand	? 200–1,000	150– 500
Digboi oil sand group	?1,000–2,000	500–1,800

Productivity.—The caliber of production varies astonishingly, especially in the Digboi oil sand group. Wells put to production at the same time, from apparently identical thicknesses of the same sand, and at the same structural level, may vary in initial production from a few barrels to several hundred barrels.

Nature of crude.—The oil is of mixed paraffine and asphalt base, and is remarkable for its high wax content, which amounts to nearly 16 per cent, and high pour point, which averages 95° F. Table IV gives the general characteristics of a typical Digboi crude. In general the crude is heavier near the margins of the pools and lighter eastward. The aromatic content of the crude varies from 15 to 24 per cent by volume.

Water.—Probably the most striking characteristic of the water production of the Digboi field is the generally low concentration of dissolved salts. In the Bappapung sandstone fresh water occurs in the western part of the field, but down the eastern pitch the sand is oil-bearing and the associated water shows an

increasing salinity eastward. It nowhere becomes more than brackish, however, reaching a concentration of only 3,500 parts per million. Nahor oil sand wells produce little water; it is more saline than the water found in the Bappapung sandstone and the concentration averages 7,500 parts per million. Digboi oil sand group waters are similar to those of the Nahor oil sand and also have a concentra-

TABLE IV

CHARACTERISTICS OF TYPICAL CRUDE, DIGBOI FIELD

Gravity, °A.P.I.	35
Saybolt viscosity at 100° F.	46.0
Saybolt viscosity at 130° F.	39.4
Pour point, ° F.	95
Flash point, ° F.	44
Color	Opaque by transmitted light, dark green by reflected light
I.P. 24/44 DISTILLATION	
Initial boiling point	60° C.
Distilling under 150° C.	16.5%
Distilling between 150°–180° C.	5.0%
Distilling between 180°–300° C.	24.5%
Distilling over 300° C.	54.0%

tion of 7,500 parts per million; an analysis of a typical water sample is given in Table V. The waters in general show an increase in chloride content in the lower sands. This may provide a means of differentiating between Digboi oil sand group and Nahor waters of similar concentrations, but water analysis does not commonly afford a reliable guide to the source of water production.

Gas-oil ratio.—Great attention has been paid to the gas-oil ratio of Digboi wells. With so many separate oil sands some of very limited lateral extent, it is impossible to make generalizations which hold good for the entire field, but there are indications of a gas cap in the highest part of the structure. The general plan

TABLE V

ANALYSIS OF TYPICAL DIGBOI OIL SAND GROUP WATER

	Parts per Million
Total dissolved solids	751
Sodium	253
Calcium	1
Magnesium	1
Chloride	118
Sulphate	3
Bicarbonate	410
Carbonate	34
PALMER CLASSIFICATION	
Primary salinity	30.5
Secondary salinity	—
Primary alkalinity	68.4
Secondary alkalinity	1.1

of marginal development has led to the postponement of drilling in the highest part of the anticline but wells already drilled high on the structure have high gas-oil ratios, though even here there is much variation. The over-all gas-oil ratio of the field is about 1,600 cubic feet per barrel, but would be much higher if measures were not taken to restrict the production of gas.

Reservoir control.—Throughout the greater part of the field the production of oil is controlled by the low permeability of the sand and is dependent on the gas dissolved in the oil. Although sufficient evidence relating pressure decline to output is not available (being exceedingly difficult to obtain in a field where the conditions are so complex as at Digboi, and where group production is practised), there is good reason to believe that the field is mostly under what Herold has described as "capillary control." This generalization does not hold good throughout the field, and at the eastern end the permeability is greater in the lowest sands, possibly because of slight shattering of the beds above the plane of the Naga thrust. In this part of the field there is evidence that hydraulic control plays an important part in the lowest oil sands, and as the oil is removed water rises rapidly up the flank and takes its place.

PROBLEMS, SOLVED AND UNSOLVED

Structure.—It may be seen in Figure 3 that as the Digboi fold is traced eastward it pitches beneath a belt of alluvium, reappearing 2 miles farther east. A resistivity survey was made in this alluvial belt and the structure suggested was later shown by drilling to have been accurately predicted (Fig. 12).

In the early days correlation from well to well was an important problem. Flush sampling was used, with a few cores, but all the sands of the Tipam sandstone stage are very similar, and detailed correlation was not easy. Heavy-

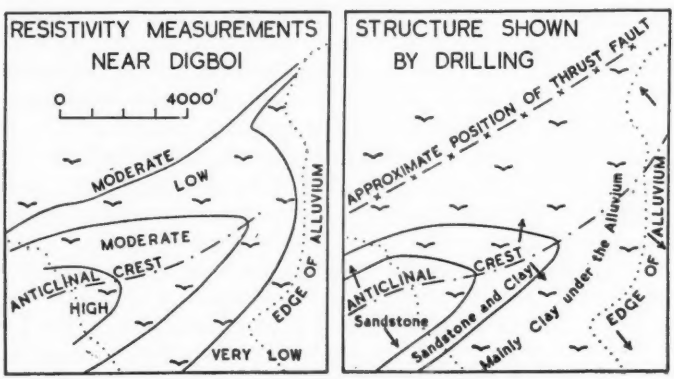


FIG. 12.—Results of resistivity survey in Digboi.

mineral analysis provided a few recognizable marker horizons but these were at wide intervals. No fossils have been found. In considering the degree of lateral variation which we now recognize it is remarkable how near the truth some of the earlier correlations were. Schlumberger surveys provided the evidence necessary to put the correlation on a firm footing, and enabled the details of the underground structure to be traced accurately. Without this method of logging the development of the field would have been considerably retarded, and much more cumbersome and expensive.

Variations in productivity.—The variations in productivity in the Digboi oil sand group have been, and still are, a troublesome problem. Some examples illustrate the degree of variation. At the eastern end of the field a well was brought in from the basal Digboi oil sand group in 1943 with an initial flowing production larger than average. Another well was drilled a short time later, while the first was still flowing much more than average; it was only 600 feet away on the same structural level, but the range was completely barren. At the western end of the field a small strip of the basal Digboi oil sand group was developed in 1945–1946. Most of the wells, both early and late, came in with a satisfactory yield, but two centrally located wells, drilled in the middle of the period, were almost complete failures. In the center of the field, three marginal wells were completed in 1935 from the entire Digboi oil sand group, leaving an infilling site between them not drilled; their initial production was poor. The infiller was drilled 3 years later and had a very satisfactory yield, much larger than the previous three wells combined.

At first it was thought that the normal method of completion by rotary, with ordinary mud, was perhaps responsible for the irregular results, and various other methods of completion have been tried from time to time. One of the earliest was wall-scraping with oil just before running the liner, but no improvement in production could be recognized. Some wells, using oil circulation, were drilled through the producing zone, but they gave results no better than adjacent wells which had been drilled with mud. Circulation was completely lost while one well in the fissured area was being drilled-in with oil; the hole collapsed, and it was not possible to drill deeper. Trials have also been made using gas-cut mud and gas-cut water, but results were not encouraging.

In 1937 two wells were completed by cable tools: one through the upper half and the other through the lower half of the Digboi oil sand group. The results of these suggested clearly that the variations in productivity were primarily due to (a) variations in porosity and permeability, and (b) group production which allowed interference between sands of different pressures. These suggestions were later supported by wells completed with plain cemented liners and put to production from limited ranges of the Digboi oil sand group through bullet perforation. Several of these wells produced much more from a limited range than adjacent wells had yielded from the whole range.

Therefore, the present policy is based on the cementation of plain liners and

producing from limited ranges through bullet perforation, low-pressure and otherwise undesirable ranges being shut off behind the pipe. Further, the quality of the mud is being continually improved so as to minimize any risk there may be of mudding-off potential productive sands.

It was thought that production from a tight sand might be improved by shooting, and an experiment was made in 1944. This showed that the practical difficulties of the operation were considerable, and no improvement in production was found in the well in which it was tried. The sands of the Digboi oil sand group contain calcareous material, and laboratory experiments suggested that acidization might open drainage channels. Two wells were treated and both showed an increase in permeability, from the evidence of rate of build-up of bottom-hole pressure. The increase was small, however, and no significant change in production was obtained.

Identification of fluid contents.—The very low salinity of the formation waters has contributed greatly to difficulties in differentiating oil, water, and gas-bearing sands in electrical logs (Figs. 13 and 14). Only in the very lowest beds has there been any success; and that only by the use of an empirical formula, based on experience, which differentiates in a general way: (a) beds almost certainly entirely water-bearing, (b) beds probably chiefly oil- or gas-bearing, and (c) beds whose fluid content is uncertain. No idea of the caliber of production can be deduced, and, in particular, beds which give the criteria for (a), or (b), or (c) may be found barren. The electrical logs are no guide at all to the fluid content of nearly 2,000 feet of possibly oil-bearing formation. As a result, therefore, much time and money unavoidably have to be spent in perforating and testing zones which turn out to be poorly productive, but which we dare not abandon without a test. The problem has been under frequent discussion and we are still experimenting with variations in electrode spacing and mud characteristics in attempts to overcome it.

Paraffination.—There are very few flowing wells and most of the wells produce by gas lift. The high pour point of most of the Digboi oil, 95° F., is a sufficient indication that one of the great problems of production has been paraffination. Attempts to prevent paraffination have not been successful, and we have come to regard it rather as a necessary evil, devoting our attention to improving methods of removing the paraffine which is deposited. In most wells regular running of a suitable scraping tool keeps the tubing fairly free from wax without interfering with production, and where this is done in a flowing well a somewhat elaborate arrangement of a chamber and stuffing box is required above the flow string. Pulling tubing is a troublesome job, and in order to clear the wax it may be necessary to blow steam through the tubing. The extra attention that is needed is a serious item in production costs, and in an endeavor to reduce the frequency of work on producing wells, and the loss in production from repeated shut-downs, the strings of tubing used have been larger than would ordinarily be necessary.

There is the obvious danger of paraffination of the sand face inhibiting the

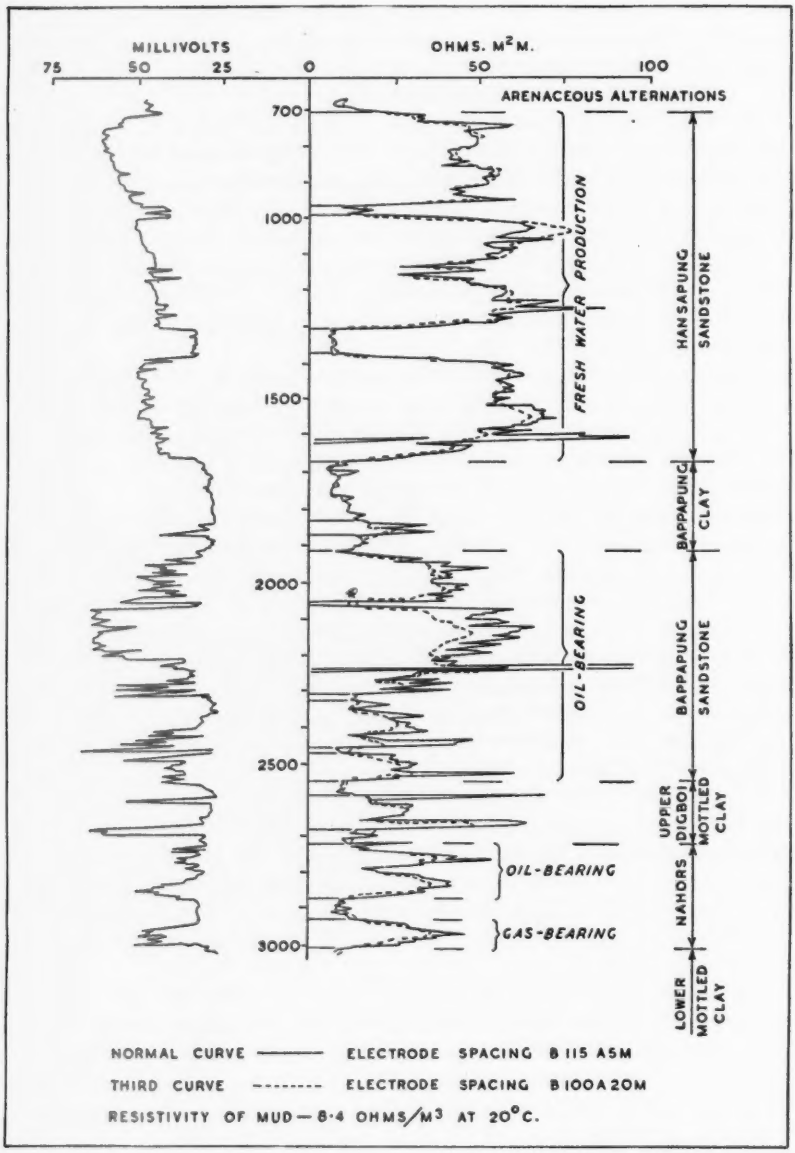


FIG. 13.—Typical electric log of upper sands, Digboi field.

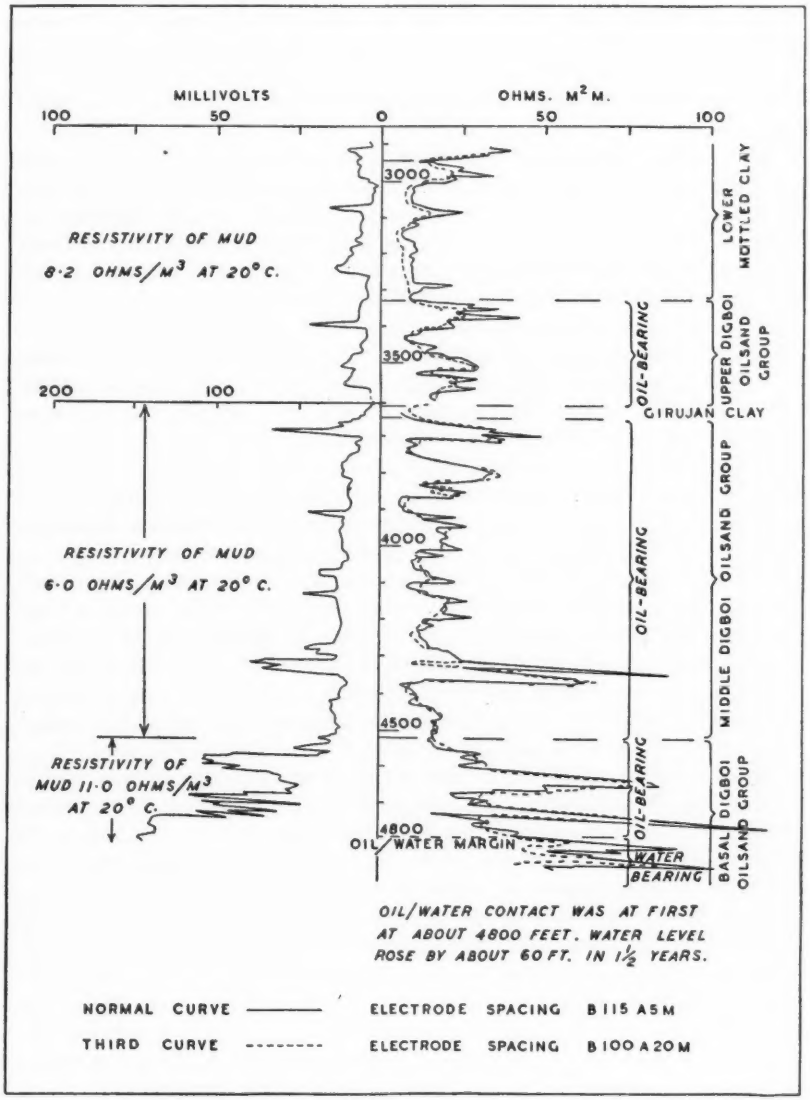


FIG. 14.—Typical electric log of Digboi oil sand group.

flow of oil into the hole. When production has declined to a low level, wells producing from the Bappapung sandstone group benefit greatly from soaking with kerosene. Production has been increased as much as 500 per cent and increases of 100–200 per cent are common. The treatment has not proved so successful with the less porous and permeable ranges of the Nahor and Digboi oil sand groups.

Sand trouble.—In the early days much trouble was experienced from the sanding of producing wells and this was overcome only by the substitution of screened for perforated liner. The slots in common use are 0.040 inch wide, but even these are too wide for some of the Digboi oil sand group, some of which cave overnight, plugging the liner with sand of grain size about 0.01 inch. Wire-wrapped screen is now used where this trouble is anticipated, but the difficulty is to decide beforehand just where it will be required.

Crooked hole.—Among drilling difficulties, the steep dips caused much crooked hole in the early days. As early as 1924 it was realized that a hole could be drilling very crooked without the driller being aware of it, and a simple inclinometer was then developed at Digboi for use in rotary wells, recording deviations of 20° and even more.

Loss of circulation.—Severe losses of circulation occur in certain sands. In some parts of the field these occur while drilling through the non-productive sands of the Hansapung sandstone and Bappapung sandstone groups. The trouble used to be dealt with by attempting to plaster off the offending zone by adding bagasse (crushed sugar cane), paddy husks, or more recently, mica and cement to the drilling mud. In present practice, a light mud is used, approximately 72 pounds per cubic foot, but the difficulties of producing such a mud from local clay sources with good wall-building properties have yet to be completely overcome. Despite all precautions, much good mud may be lost before a troublesome 50-foot zone can be penetrated.

In some parts of the field severe losses of circulation occur in the lower productive beds of the Digboi oil sand group. They are almost certainly due to the presence of more than normal fissuring, related either to the proximity of the Naga thrust or to the alignment of the structure making a sharp bend. These losses are a more serious problem and in some wells it has been possible to drill through the zone only with the loss of many hundreds of barrels of mud. It is not known what effect these losses have on the productivity of the sand. It is thought, however, that a zone which will so easily take mud, will just as easily flush itself clear of mud when brought to production. At the same time it is an expensive and undesirable business. The use of plastering materials must, of course, be avoided, and it is necessary to rely on suitable low-weight muds. Possibly the ultimate solution is to be found in the use of oil-base or emulsion-type muds.

Sticking of pipe.—A factor which has influenced completion policy is the difficulty of withdrawing a liner once it has been run into a hole for a production test. Consequently, it has been necessary first to drill and case a well to final

objective; it has not been possible to drill ahead by short stages, testing as the hole deepened. This is not of such importance now that it is possible to cement a plain liner and test stage by stage through bullet perforation, but it was a great handicap in earlier days. The policy was to run $5\frac{3}{4}$-inch liner into $9\frac{1}{2}$-inch hole, and even a short length run in for a test was almost certainly there permanently. The cause is probably the rapid influx and settling of sand around the liner once the mud has been removed from the hole. When drill-pipe is twisted off while drilling through a zone of lost circulation, there is a similar danger that the reduced head of mud will permit sand to settle around the fish and cause it to stick. There is no particular evidence that liners or drill-pipe tend to stick in a hole which is kept full of good mud. Fishing jobs ordinarily are not difficult, and rat-hole formation tests are frequently made but rarely give any trouble.

Migration of oil.—In conclusion, we may perhaps speculate briefly on the mode of accumulation of the oil in the Digboi structure. It is generally agreed that the oil came from the underlying Barail rocks. Whether they provided the actual source rocks is not yet clear; they may only have been a temporary resting place for the oil on its journey. They do, however, include carbonaceous shales, the organic contents of which under suitable conditions may have been transformed into petroleum, just as under other conditions the prevailing vegetable matter was transformed into thick deposits of coal. Throughout Upper Assam the Barail is characterized by oil showings. On the contrary, the Tipam sandstones include nothing remotely suggestive of source material. They are a series of medium- to coarse-grained sandstones, with mottled clays, remarkably free from organic material of any kind. The rocks of the Surma series in this area are also unpromising as source rocks. Oil showings in these two series, although plentiful in some places, are more restricted in distribution.

Digboi is an area where: (1) the reservoir rocks of the Tipam series were folded into a suitable anticlinal trap; (2) the Surma series is absent, and movement of oil from the underlying Barail was facilitated by migration upward "through the hole in the roof" into the trap; (3) the anticline has been preserved and is not deeply eroded, as are other Assam folds from which most of the oil has probably escaped; and (4) the Naga thrust is present to assist in the migration of oil from the Barail to the Tipam; but it is not clear to what extent this channel, up which the oil could flow, was fundamentally necessary.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 1 (JANUARY, 1949), PP. 22-31, 2 FIGS.

STRATIGRAPHY OF SOUTHEASTERN TURKEY[1]

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ABSTRACT

In the stratigraphy of southeastern Turkey the Paleozoic is represented by more than 2,000 meters of Cambro-Ordovician composed largely of micaceous sandstones, some siliceous limestones and pyroclastics in the region of Telbesmi, west of Mardin, and by limestones and marly limestones of Permo-Carboniferous age in the eastern part of the area. The basal quartzitic part of the latter contains forms suggesting Upper Devonian age. The Permian underlies the Triassic without an unconformity. The Mesozoic section, which is principally calcareous, maintains that facies to the middle of the Cretaceous. The Upper Cretaceous is composed principally of argillaceous shales which continue into the Paleocene. The lower part of the Eocene is arenaceous, but the Lutetian is an extensively developed thick limestone. The upper part of this limestone is chalky and soft. This latter part is considered upper Eocene and may extend even higher. The Miocene is represented by siliceous and gypsiferous limestones and shales. The very extensive development of the Pliocene in the continental facies suggests similarity to the Bakhtiari series of Iraq.

For the purposes of this discussion the boundaries of the area are delineated as follows: Syria and Iraq in the south, Iran (Persia) in the east, a line passing through Pervari and Shirvan to the Euphrates in the north, and the Euphrates River in the west. Of the five tectonic units into which Turkey has been divided the two, namely, the Foreland zone and the Iranides, are wholly or partly represented in the area (1, 3, 5). The country is generally mountainous and only near the Iraq-Syrian frontiers is the topography rolling or flat. The elevation of the Plains area, on the Turkish side of the boundary, is approximately 500 meters. But as one travels north or east one crosses higher and still higher ranges, reaching altitudes between 3,000 and 4,000 meters in the east and 2,000–3,000 meters in the north. The Cilo Mountains west of Gevar (now called Yüksek Ova), with the Resho at 4,160 meters (13,644 feet), have the third highest peak of Turkey.

The oldest rocks of the region are considered to be the quartzites and mica schists found in the undifferentiated Hakari complex. Studies in the Pervari region disclosed some mica schists and quartzites below the Permo-Carboniferous. The Cambro-Ordovician section of Telbesmi contains in its lower parts highly indurated sandstones and felsites which have been referred to the Algonkian.

PALEOZOIC

At Telbesmi west of Dirik in the Vilayet of Mardin pre-Cretaceous intrusives cut ancient-looking sedimentary rocks. The Mardin anticline, which exposes Turonian limestone in that locality, rises westward bringing the lower parts of the Cretaceous to view in the precipitous scarps near Dirik. At Telbesmi a fault brings to the surface a thick section of sandstones, marls, limestones, conglomerates, quartzites, and felsites totaling 2,285 meters. The section is separable into the following units, starting from the top.

[1] Manuscript received, September 27, 1948.

[2] M.T.A., Petrol. Grubu.

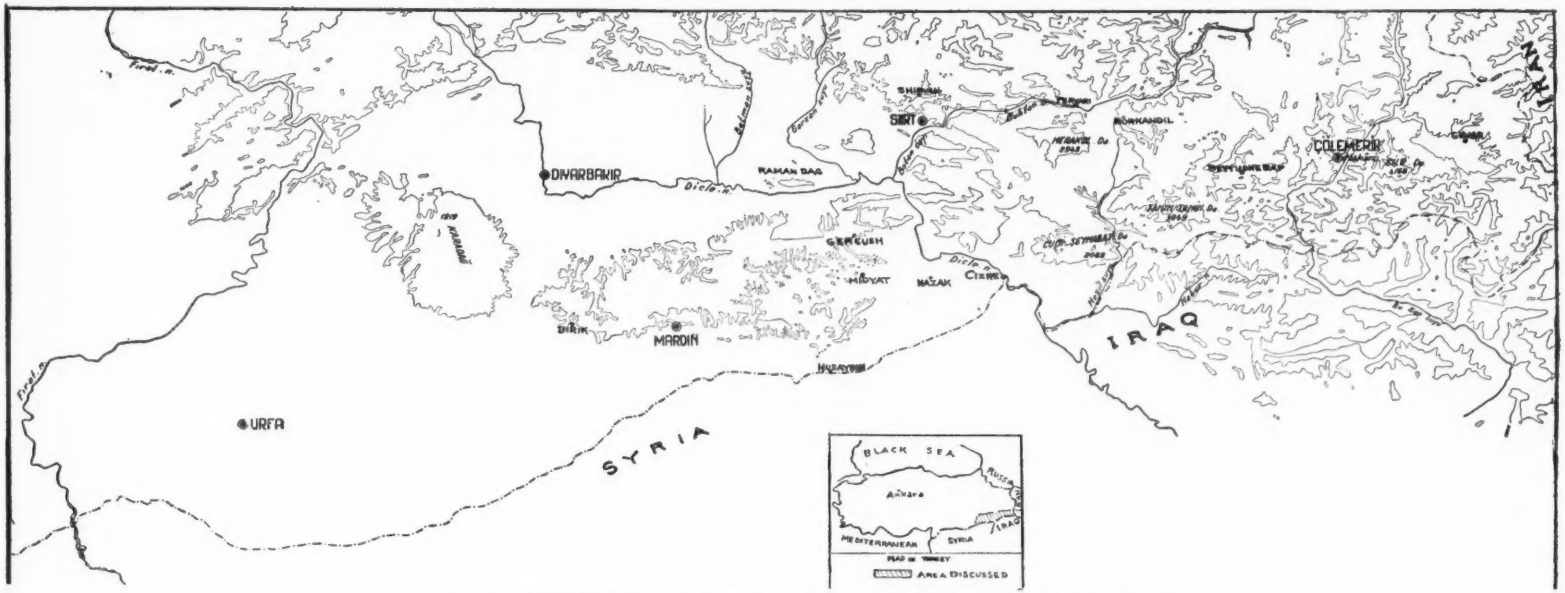

FIG. 1.—Topographic map of area. Contour interval: 1,000 meters. Scale: 1:2,622,000 approx.

Thickness (Meters)	
590	Coarse- and fine-grained light gray sandstones with trilobite fragments
155	Transition series. Micaceous marls grading upward into sandstones. Near bottom, reddish gray marly limestone. Glauconitic and calcareous sandstones in upper part contain trilobite fragments
195	Hard siliceous bluish dark gray limestone with both concretionary and vein chert. Sandstones near base
430	Cross-bedded sandstones, pinkish at top, cream-colored in middle, and dark red below
45	Thin-bedded reddish sandstones and greenish conglomerates with subordinate development of argillaceous marls
60	Thin-bedded, dark gray, hard, metamorphosed limestone with thin-bedded sandstones and red chert
55	Red and green conglomerates with large angular volcanic pebbles. Sandstones with red and green speckles
110	Metamorphosed sandstones with dark reddish quartzites and igneous apophyses
645	Felsites, vesicular basalt, dark hematitic sandstones. Base not observed

H. F. Moses refers to this section as pre-Carboniferous but other geologists have considered it Cambro-Ordovician.

In the region of Harbol, near the Iraq boundary, the Paleozoic was first noted independently by Shirley Mason (9) and Djevad Eyoub (4). Subsequent work by Maxson, Foley, Blumenthal and Erk, and others not only has confirmed the presence of the Permo-Carboniferous in this area but also the presence in the section of undoubted Triassic above and probable Devonian below. The Paleozoic section of Harbol, which is nearly 600 meters thick, has at its base brown quartzitic limestone with a small amount of shales and thick- and thin-bedded dark gray conchoidal argillaceous limestone above. The latter contains *Productus semireticulatus*, *P. gigantus* and *Fusulinella sp.?*. The thin-bedded limestones above, with a thickness of 250–300 meters and containing *Mizzia velebitana*, *Productus horridus*, and *Derbyia armenica*, are referred to the Permian. These beds, without showing an unconformity, enter into the Lower Triassic (Werfenian).

About 25 kilometers south-southeast of Hakari, between the villages of Nebaf and Kunderes, along Han Creek flowing east from Giri Dag, a thick section composed principally of quartzites underlies the Lower Triassic. The name of Giri quartzite was adopted by J. H. Maxson for this section. Though no fossils were found, the formation is conceded to be Paleozoic. It contains 200 meters of reddish brown quartzite underlain by 250 meters of thin-bedded dark ochercolored quartzite. Below these are 75 meters of green argillite and 25 meters of dark gray and white limestone. The base has not been observed.

In Pervari, unconformably overlying the mica schists, is a calcareous section containing Fusulinidae which can not be precisely identified because of their crystallized condition. The section has been referred to the Permo-Carboniferous.

In adjacent Iraq and Iran the development of the Paleozoic has been described by Lees (7, 8) in the Bakhtiari Mountains 150 kilometers east of the Mesdjidi Suleyman oil fields. Here, a section 2,000 meters thick, composed of red sandstones in the upper part with reddish and greenish shales and dark dolomites below is referred to the Cambrian, and the quartzites above with thin-bedded green and dark shale intercalations are considered Devonian. Also in the Bakhtiari

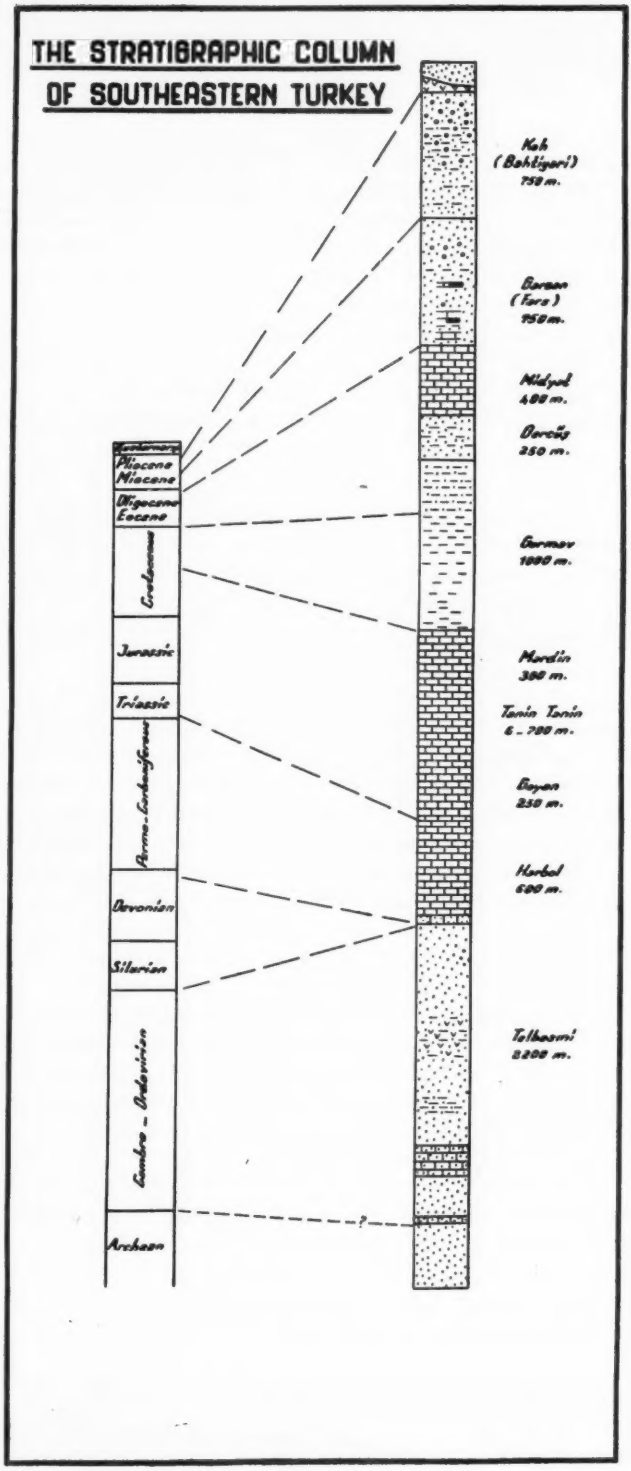
THE STRATIGRAPHIC COLUMN
OF SOUTHEASTERN TURKEY
Kah
(Bahtiyari)
750 m.
Beraan
(Fars)
750 m.
Midyat
400 m.
Derdin
250 m.
Germav
1000 m.
Mardin
350 m.
Tanin Tanin
6 - 700 m.
Bayan
250 m.
Harbol
600 m.
Telhasmi
2200 m.
Quaternary
Pliocene
Miocene
Oligocene
Eocene
Cretaceous
Jurassic
Triassic
Permo-Carboniferous
Devonian
Silurian
Cambro - Ordovician
Archaean
?

FIG. 2

Mountains, brown calcareous sandstones of Westphalian age underlie a calcareous series. This Permo-Carboniferous section passes into the Triassic without a break. The similarity in the development of both the Cambrian and the Devonian in Iran to the Telbesmi and Harbol sections in Turkey, and the transitional passage from the Paleozoic into the Triassic in both countries are noteworthy.

At El Gara Mountains, 375 kilometers west of Bagdad, in Iraq, Paleozoic rocks range from the Devonian to the Permian. In Syria at Cebel Abdülaziz, Dubertret mentions the presence of Lower Carboniferous (Tournaisian).[3] Both Cebel Abdülaziz and El Gara are directly south of Telbesmi. Frederick G. Clapp (2) referred to the Cambrian along the eastern shore of the Dead Sea.

MESOZOIC

In this area rocks of Triassic, Jurassic, and Cretaceous age have been determined. The lower part of Mesozoic, from Triassic to Middle Cretaceous, is composed largely of limestones and dolomites, whereas the Senonian and Maestrichtian are in the argillaceous facies, being composed of clay shales and marls. Hence, lithologically the Mesozoic may be separated into upper and lower divisions.

LOWER MESOZOIC

In the region of Harbol the Permian and Lower Triassic (Werfenian) are conformable. J. H. Maxson observed the presence and the great extent of the Triassic at Goyan in 1936, and gave the name of Goyan formation to a section composed, with the exception of 20 meters of chocolate shales, entirely of limestone. This formation can readily be recognized in the field both lithologically and faunally. Arni and Stchepinsky determined *Pseudomonotis clarai* and *Myophoria ovata* from the Maxson and Blumenthal collections brought from Goyan. Yellowish bands of marly limestone give a characteristic appearance to this formation when observed from a distance. The section contains a small amount of greenish sandstone with glauconite.

Above the Goyan formation generally dark dolomitic limestone is 600–700 meters thick. It emits a fetid odor on fresh fracture. This formation is well developed in the Tanin Tanin Mountains at Hilal and Chemheski and is given the name of Tanin Tanin. The presence of *Halobia halorica* suggests a resemblance to the Ladinian and Norian of the eastern Alps. This formation which is undoubtedly Triassic in age in its lower parts includes the Jurassic and probably even the Lower Cretaceous in the upper part. It covers large areas east of the Tanin Tanin Mountains. The corresponding section at Harbol has been measured from top to bottom as follows.

Thickness (Meters)	
830	Limestones. Dark gray or black in lower part and light gray in upper
115	Fine-grained gray-weathering brown limestones with dark shale intercalations

[3] I.P.C. geologists have come to the conclusion that the presence of the Carboniferous at Cebel Abdülaziz is due to submarine landsliding during the Mesozoic.

40 Dark reddish shale with greenish gray hard shale and quartzite intercalations 10–30 centimeters thick

100 Calcareous section of thin (2–5 centimeters) gray and pinkish gray beds with Lower Triassic fossils emitting fetid odor on fresh fracture. Immediately above Permian

From the top of the Permian to the base of the Senonian, Germav shales, averaging in thickness 1,000 meters, occur in the Harbol-Shirnak area. A well at Gercüsh, beginning from the top of the massive Turonian limestone, penetrated 635 meters of limestone without reaching the base. The thinning of the section toward the west may be expected. This section, which from the Triassic to the Middle Cretaceous is largely in the limestone facies, has a similar characteristic on the other side of the boundary at Seramadiye and north of Zaho, and a comparable thickness of 900–950 meters.

A fault near Shirish, between Drahini and Goyan, extending northwest and southeast, brings to the surface massive dark gray limestone with calcite veins. It has a thickness of 150 meters, the upper third of which is in bands one meter thick. At the top, which is dolomitic, the Goyan formation is found without any unconformity. In the Harbol region the same conformable relationship between the Permian and the Mesozoic has already been noted. The passage from the Paleozoic into the Mesozoic without a break in Iran has been mentioned by Lees (7) and others. Some geologists have been tempted to find a hiatus on the Turkish side of the frontier, but careful work has indicated that there is no sound reason for this supposition and the local evidences obtained point rather to a possible break between the Triassic and Jurassic instead of a hiatus between the Paleozoic and Mesozoic.

The uppermost part of the thick Mesozoic section is observed at few places west of the Tigris and Bohtan rivers, but it has an extensive development east of these rivers. One of the areas in the west is at Mardin where the massive limestone with *Hippurites gosaviensis* and *H. cornu-vaccinum* has been referred to the Senonian. But, on the basis of certain *Orbitoides* and *Amphalocyclus* which occur at the boundary between the Senonian and Turonian in Egypt, Tromp has considered this formation as Turonian. These forms are found at the top of the massive limestone and in the marly intercalations overlying it. The Turonian age is generally accepted in Turkey for the upper part of the massive limestone which we are calling Mardin limestone because of the very good exposures in that locality and also because this formation was studied there first. Besides the *Hippurites* mentioned, *Radiolites*, *Caprina*, and *Inoceramus* have been found in the upper parts of the limestone. More than 300 meters of the upper part of the Mesozoic limestone crops out at Mardin.

Overlying the massive Mardin limestone, flaggy beds composed of intercalation of shales, marls, and limestones, and containing *Inoceramus balticus*, transitionally pass upward into the Germav shales. Louise Jordan has described the fauna of these transition beds from Gercüsh as follows, from top to bottom.

Flaggy beds	*Inoceramus balticus*
	Ammonites
	Cyclolites
	Orbitoides

Orbitoides bed	*Orbitoides media* *O. apiculata* *Siderolites vidali* *Rotalia* *Globigerina* *Cibicides*
Mardin limestone	*Orbitoides sensu stricto* *Rudistid* *Cyclolites* *Gastropods*

The transitional flaggy beds which may be referred to the Campanian thin out and disappear toward the east. At Körkandil Dag, east of Bohtan Su, a 20-meter conglomerate and nodular sandstone bed overlies the massive Mardin limestone. The interval between the Mardin limestone and the Germav shales is thus represented by continental deposits, indicating a condition at the end of the Mardin limestone deposition during which the induced porosity of this limestone, as in Raman Dag, assumably developed. The Mardin limestone at this locality has been eroded to the *Hippurites vesiculosus* zone.

North of Cudi Dag, near Kirandul, the relationship between the massive Mardin limestone and the overlying Germav shales is also marked by a hiatus. Immediately above the limestone the transitional beds are lacking, and we find instead the Germav shales with *Pachydiscus isculensis* and *Neithea quinquecostata.* The Mardin limestone contains *Hippurites loftusia* and *H. vesiculosus.* The time of the transgression was apparently during the Campanian. The serpentine intrusions at Minar, west of Siirt, are post-Turonian and probably Campanian in age.

The flaggy beds pass upward into the argillaceous Germav shales in the Gercüsh part of the area without a break. However, the wells at Raman Dag show a 40–50-meter bed of red and green arenaceous marls which correspond with the flaggy beds of the Mardin and Gercüsh areas.

The overlying Germav shales have an average thickness of 800 meters at Raman, 900 meters at Kerbent, and 700 meters at Basbirin. The upper part is arenaceous in some sections but otherwise it is composed entirely of marls, shales, and clay shales. The formation is Senonian in its lower part and Paleocene in the upper. There is no observable lithologic difference to the naked eye, where the Cretaceous passes into the Paleocene, and the micropaleontological evidence is invariably the sole criterion. It has been the custom to consider the presence of some or all of the following as an index for the Cretaceous: *Globotruncana*, *Gümbelina* (large ones, left over 0.2 mm. mesh), *Bolivina incrassata*, and *Pseudotextularia.* The last two apparently have a very wide range as they are used as an index for the Cretaceous in Texas also. The Germav shales in the region of Beytushebap are found metamorphosed into a schist as a result of the severe local thrusts.

TERTIARY

The passage of the Cretaceous into the Tertiary as noted is transitional. The part of the Germav shales above the *Globotruncana* marker is considered Paleo-

cene and lower Eocene. This and other markers cease to exist in the wells and we begin to find *Globorotalia* and *Textulariella* instead. In the field, however, the sandy glauconitic bed in the upper part of the Germav is used as the beginning of a new sedimentation condition and is believed to indicate the passage from the Cretaceous into the Paleocene.

The reddish gypsiferous beds above the Germav are primarily sandy with marl and limestone intercalations. This formation is known as the Gercüsh formation. In the type locality which is at Gercüsh, 20 kilometers north of Midyat, the section begins with a calcareous member, is followed by a fairly thick reddish member, and is topped with gray and yellowish marls. It has an average thickness of 250–300 meters, thinning out east of the Tigris as well as toward the west near Mardin. Southeast of Beytushebap the middle Eocene Midyat limestone is found directly overlying the Germav series. Near Siirt and Harbol, the Gercüsh formation contains conglomerates and gypsiferous marls. Apparently there was a regression of the sea during this period in this region. Because of the reddish color, the presence of gypsum, and its extensively sandy character, the Gercüsh formation has been considered a continental deposit. However, in the Ramon Dag area the Gercüsh formation contains marine fossils in the limestone intercalations, indicating oscillation of the sea shore. At the end of the Cretaceous when the sea with an uneven floor began to recede, topographically high places emerging first gave an opportunity for the development of the conglomerates and sandstones, with less elevated parts remaining below sea-level, bringing about the irregular distribution of the marine intercalations in an otherwise mainly continental deposition.

The calcareous intercalations of the Gercüsh formation contain *Nummulites parvulus*, *N. praelucasi*, *N. burdigalensis*, and *Lockhartia*, which assemblage indicates the upper part of the lower Eocene in this region. Above the reddish member of the Gercüsh formation and below the Midyat limestone the cream-colored marls contain *Rotalia trochoidiformis* and *Lockhartia conditti*.

In the region of Urfa, the equivalent of the Gercüsh formation is in the facies of a white chalky marl 350 meters in thickness and containing lower Eocene macrofossils and microfossils.

MIDYAT LIMESTONE

Near Midyat light yellowish marly chalky limestone is developed extensively in southeastern Turkey, being the surface formation of many of the high mountains of the area. It has a soft marly upper part and a cliff-building, hard, massive lower part. Besides some echinoids which have been found to serve as a very satisfactory local index at Raman Dag, *Nummulites*, *Orthophragmina*, *Operculina*, *Assilina*, and *Miliolidae* are found. Its outcrop at the Kasrik Gorge, near Cizre, where the entire section is standing nearly vertical, gives the geologist a very good opportunity not to study the Midyat limestone alone but also its relation to the upper and the lower formations. It is equally well exposed at Raman Dag and in the Gercüsh valley. It has a thickness between 300 and 400

meters. The wells in the higher topographic part of Raman Dag structure penetrate an average of 270 meters of Midyat limestone, whereas at Basbirin the well logged 360 meters of limestone before reaching its base. The different results are due to the fact that the wells start from different horizons of the formation. At the Basbirin well the Midyat limestone had the following characteristics from top downward.

Thickness (Meters)	
167	Light gray cream-colored limestone with *Nummulites, Alveolina, Miliolidae*
55	Non-fossiliferous dolomitic limestone
22	Light gray fossiliferous limestone
116	Dolomitic and marly limestone

At Bikat, east of the Bohtan and Tigris rivers, Arni found the following forms in the Midyat limestone: *Nummulites lavigatus, N. burdigalensis, N. subaticus, N. gallensis, Assilina spira, Gypsina globulus, Flosculine,* and *Alveolina.* Near Mardin the Midyat limestone appears to have thinned out. Farther west, between Urfa and the Euphrates River, it may be compared with the cream-colored chalky middle Eocene limestone which has an average thickness of 250 meters in that area.

MIOCENE

In this area the Miocene is in the chalky facies near Urfa, as gypsiferous and varicolored marls and sandstones near Osmaniye, in the gypsiferous limestone and limestone form around Siirt, and principally continental east of Cizre, near the Iraq boundary.

Near Urfa, a section of white, yellowish, pinkish limestone 80–100 meters in thickness, and rich with *Operculina,* locally is known as *Operculina* limestone. Besides *Operculina,* the formation contains *Heterostegina, Lepidocyclina,* and *Spiroclypeus.*

At Osmaniye, 60 kilometers northwest of Diyarbakir, the Hushut basin contains gypsiferous sandstones and reddish greenish marls overlying the white limestones seen at Malikan. In the Malikan limestone, Chaput found the following forms: *Miogypsina inflata, Amphistegina radiata,* and *Lepidocyclina.* He considered the limestone as Burdigalian and the overlying gypsiferous series as Vindobonian, comparing them with the Asmari limestone and the Fars series of Iraq and Iran.

The Miocene near Beshiri and Siirt is composed of a gypsiferous series below with a limestone above, just the opposite of the situation cited for the Hushut basin. The limestone above is pinkish, brecciated, coral limestone with opaline structure and is 100 meters thick. It is called the Garzan limestone. The lower gypsiferous series is composed of three parts. At the top are pinkish marls with gypsum 150 meters thick, followed by a 25-meter bed of massive limestone, and at the base are thick gypsum beds with minor limestone intercalations. In the Garzan limestone, near the bridge across the Garzan stream, a rare specimen has

been found which has been determined as *Heliastraea deferanci*, indicating Miocene. The Midyat limestone underlies the Miocene section without an apparent break.

At Tur Abidin Mountain, north of Nusaybin, and at the Kasrik Gorge the Lutetian Midyat limestone appears to go higher in the section, containing forms younger than Eocene, even Oligocene. At Cebel Ebyaz, and near Kufuh east of Hezek, from a collection of ten samples from the upper part of the so-called Midyat limestone, four have shown Miocene characteristics. The Midyat limestone at the Kasrik Gorge, measured to be 840 meters thick, apparently also extends up to the Burdigalian. This situation of the Eocene Midyat limestone extending to the lower Miocene needs further study. It may be helpful to remember that though the Asmari limestone in Iran is lower Miocene, the assumably equivalent formation producing oil in Iraq has been found to be Oligocene and Eocene in age.

PLIOCENE

The Garzan limestone is overlain by shales, sandstones, and conglomerates. At the foot of the Bitlis Mountains, from Ziyaret to Koh, this section is found to have fairly steep dips. Here, its minimum thickness is 800 meters. Along the Hizil Su, separating Turkey from Iraq, the same formation attains a thickness of several thousand meters. Near the base some lignite beds are found. The section appears to be the counterpart of the Bakhtiari across the boundary in Iraq and Iran.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 1 (JANUARY, 1949), PP. 32-51, 15 FIGS.

FRACTURED RESERVOIRS OF SANTA MARIA DISTRICT, CALIFORNIA[1]

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ABSTRACT

Cumulative production of the Santa Maria district to January 1, 1947, was 250,637,000 barrels, of which an estimated 77 per cent was from fractured rocks and 23 per cent from oil sands. Seventy-four and one-half per cent of the oil was produced from fractured rocks in the Monterey formation and 2 per cent from fractured Knoxville sandstones. Monterey fractured rocks in order of importance include (1) Mohnian cherts, (2) Luisian calcareous shale, and (3) Mohnian platy siliceous and porcellaneous shale. The distribution, age, and character of fractured zones are illustrated by stratigraphic sections. The distribution of maximum chert development suggests chert originated as a sedimentary facies. General characteristics of potentially productive fractured rocks of the district are analyzed and their permeabilities and porosities, as indicated by production data, are discussed.

INTRODUCTION

The Santa Maria district produced 250,637,000 barrels of oil to January 1, 1947. In all, 192,000,000 barrels, or 77 per cent was produced from various types of fractured rock and only 23 per cent was produced from sand. The district offers a classic example of production from fractured rocks and a fertile field for the study of types and characteristics of rocks which are potentially fractured.

Figure 1 illustrates the stratigraphic position of the types of reservoirs in the district and the economic importance of each.

The stratigraphic position of oil sand zones is indicated by Column 1.

Column 2 portrays the position of fractured shale reservoirs, a group of zones which has produced 74.2 per cent of the oil. Fractured shale zones are productive in all fields of the district.

Column 3 illustrates the stratigraphic position of fractured sandstone zones. These include (1) fractured calcareous sandstones of the Point Sal formation, productive to a very minor degree at the east end of the Santa Maria Valley field, (2) fractured calcareous sandstones of the Lospe, productive in the Arrellanes pool of the Casmalia field, and (3) most important, fractured calcareous sandstones referred to the Knoxville[4] formation and productive in the north-central part of the Santa Maria Valley field. The last two sandstones are older than known local source beds. The accumulation of oil in these rocks is similar to the fractured basement accumulations in other districts. These zones have produced 2.4 per cent of the oil in the Santa Maria district.

Some of the characteristics of fractured zones in the district are as follows.

[1] Read before the Pacific Section at Pasadena, California, November 6, 1947. Manuscript received, August 26, 1948. Published by permission of C. M. Wagner, General Petroleum Corporation, and L. N. Waterfall, Union Oil Company of California. Credit is due A. J. Taylor, Santa Maria, California, for the photography.

[2] Geologist, State Exploration Company, Bakersfield.

[3] Paleontologist, Union Oil Company of California, Santa Maria.

[4] In this article, Knoxville is used tentatively in correlating these sandstones.

EXHIBIT

PRODUCING ZONES OF THE SANTA MARIA DISTRICT

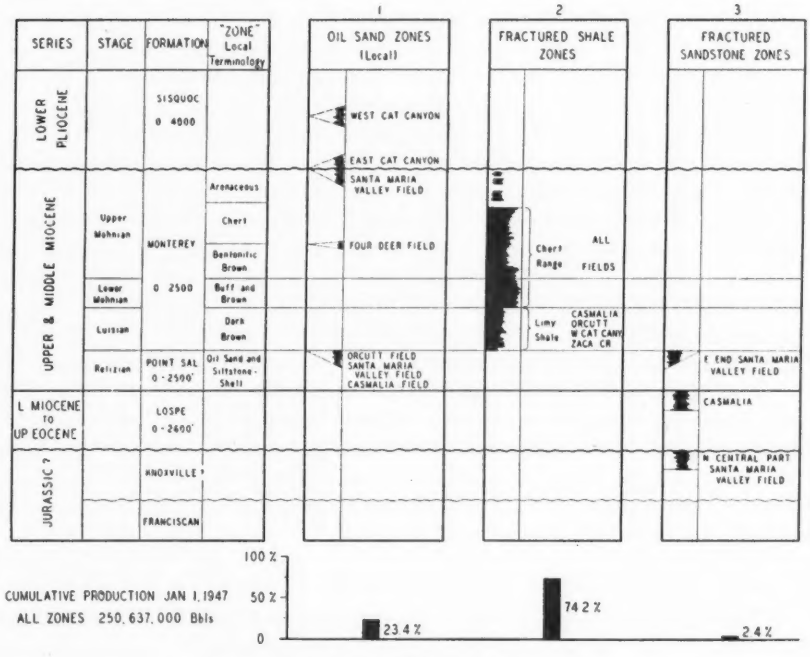


FIG. 1.—Producing zones of Santa Maria district.

1. Potentially fractured reservoirs, meaning zones most susceptible to fracturing, are composed of very brittle, hard, generally conchoidally fracturing rocks. These rocks include in order of importance: (1) chert, (2) calcareous shales and shells, (3) platy siliceous shale, and (4) sandstones. It appears that the harder and more brittle rocks have better potential development of secondary porosity and permeability by fracturing.

2. Productive fractured rocks commonly exhibit favorable reservoir character on the self-potential curve of an electric log. The amount of relief shown by the curve can not be taken as an index of productivity of a well, but a very flat self-potential curve indicates either a tight, poorly fractured zone, or one in which the fractures are sealed by tar. The resistivity of a fractured zone in this district is generally high on all curves regardless of fluid content because of the dense character of the rock.

3. Indications of oil when drilling and coring potentially productive fractured reservoirs are unimpressive. Core recovery is commonly poor and may be limited

to a few fragments. Most of any oil present is washed away or driven out of the core into the formation by the drilling fluid. Showings generally are limited to a little free oil on the fracture planes and in the drilling fluid. Some cores in tight or only incipiently fractured zones show more indications of oil than cores in well fractured zones. Ditch cuttings from productive, fractured intervals are commonly oily. These factors are useful in determining the presence of oil, but obviously are not a key to the development of porosity and permeability.

4. The drilling rate is not a reliable indication of porosity and permeability, because of fracturing. Commonly a fractured zone is drilled slowly and many bits are required because of the abrasive character of the material.

5. The most reliable evidence of favorable reservoir qualities in a fractured rock is the loss of drilling fluid. The converse of this statement is not true, because many prolific wells have been drilled in such zones without appreciable loss of fluid. The loss of fluid in some places has been extreme and as much as 30,000 barrels of fluid have been pumped into the formation. Wells in which circulation was lost are characterized by very high initial production rates.

Formation tests may be useful in evaluating the reservoir character of a fractured zone where the oil is not too heavy and viscous. In heavy-oil areas, recovery of water from a formation test would be conclusive, but the absence of water may not give a reliable indication of the productivity of a zone. In the final analysis, the evaluation of a potentially productive fractured reservoir requires production tests of some duration.

MONTEREY FRACTURED ZONES

The Monterey fractured shale zones indicated in Figure 1 are classified and described in order of economic importance: (1) chert zones, (2) calcareous shale zones, and (3) platy siliceous and porcellaneous shale zones.

1. The chert zones are confined to the Mohnian stage. The character, development, and age of the chert in this stage are variable, and a generalized description of the zones can best be accomplished by the use of three type sections: (A) the Santa Maria Valley field, (B) the West Cat Canyon field, and (C) the Lompoc field.

A. The Santa Maria Valley chert is upper Mohnian in age and occupies the "cherty zone" and part of the "bentonitic brown zone" of local terminology. It consists of interbedded brown opaline chert and brown and black siliceous shale with rare streaks of light gray to white opaline chert in the lower part. The actual percentage of chert has not been determined because of poor core recovery, but chert is estimated to comprise an average of less that 50 per cent and locally as low as 10 per cent of the section. The appearance of an unfractured part of a typical core in the Santa Maria Valley chert is illustrated by Figure 2 which shows the dark brown banded appearance of the Santa Maria Valley type chert. Figure 3 shows the fractured light gray to white opaline chert and siliceous shale.

B. The West Cat Canyon chert is lower Mohnian in age. This section shows

greater values on electric logs and larger amounts of chert in ditch samples than the other type sections. Figure 4 illustrates part of a core from the fractured chert zone at West Cat Canyon. The West Cat Canyon chert section consists of interbedded dark brown to black siliceous shale, gray white and black opaline chert, buff phosphatic shale, and lentils of very massive buff siliceous limestone. Opaline chert appears to comprise 50–60 per cent of the lower Mohnian section at West Cat Canyon, based on counts of chert fragments in ditch samples. The amount of siliceous limestone in the lower Mohnian has not been determined. It is gray-brown to buff in color, massive, very hard, and in cores is generally moderately fractured. Oil is contained in small solution cavities in rocks of this type, as indicated by Figure 5, and secondary permeability of this type may be locally important.

C. In the Lompoc field, chert is in both the upper and lower Mohnian, and a complete section of Monterey is present. A thin zone of brown shale is present at the top and is underlain by three fairly distinct cherty members. The lowest chert member is similar to the Cat Canyon chert with which it is correlated. The upper two cherty members are believed to be upper Mohnian in age and equivalent to the Santa Maria Valley chert, but are lithologically dissimilar to other sections. For the purpose of this paper, the two upper cherty members are called the Lompoc type cherty shale.

The Lompoc type cherty shale consists of 90–95 per cent thin-bedded, brown siliceous shale, with rare thin lenses of white and brown opaline chert and buff siliceous limestone. The lower part consists of gray to light gray siliceous to porcellaneous shale interbedded with light gray and white opaline chert, with chert more abundant.

2. The calcareous shale type of fractured zone is in Luisian rocks in much of the district, and consists essentially of brown silty phosphatic shale with interbeds of calcareous shale and limestone. The calcareous streaks give large values to the resistivity curve and relatively small throws on the self-potential curve of electric logs. This interval is in places identified as chert on the basis of electric logs, but ditch samples and cores indicate little or no chert in the zone. The relative importance of these rocks is not known because of the absence of selective tests, but cores in the zone at favorable structural position show oil. The interval is open in many structurally high field wells.

3. Platy siliceous and porcellaneous shales are of minor importance as fractured reservoirs. These shaly members of the upper Mohnian are sufficiently fractured to be productive in the Santa Maria Valley, Casmalia, Orcutt, and West Cat Canyon fields. The permeability in this type of material is generally not sufficient for commercial production of the typical heavy Santa Maria crude. Lighter oil of the Orcutt area has been successfully produced from this type of fractured zone in the newly discovered Four Deer area. The distribution, variations, and limits of types of Monterey fractured zones are illustrated by stratigraphic section (Figs. 7–11). The locations of the sections are shown on the index map (Fig. 6),

which also indicates the position of the Santa Maria oil fields and structure contours on the base of the Pliocene in the fields. The Monterey basin is delineated on this map. The areas considered as positive or nearly positive during Monterey time are the following.

1. Nipomo Mesa north and northeast of Santa Maria Valley field
2. Basement ridge in the vicinity of East Cat Canyon field
3. La Laguna basement high east of Gato Ridge field
4. Santa Ynez uplift which marks south limit of Santa Maria basin
5. Point Sal uplift

Stratigraphic section *AA'* (Fig. 7) is an approximately west-east section from the Point Sal positive area through the center of the district to the basement ridge in the East Cat Canyon area, a distance of 17 miles. Monterey type sections of the Casmalia, Orcutt, and Cat Canyon fields are shown in section *AA'*. The character and age of Monterey fractured zones are fairly uniform east and west through the center of the district. This is well indicated by an electric-log correlation, although the distance between wells is great, and also by the position of the top of the lower Mohnian. The chert in this part of the district is mainly the lower Mohnian Cat Canyon type or type 1-B. This chert is thickly developed in the West Cat Canyon field, thins across the Orcutt structure, and reaches maximum development in the Casmalia field. The chert thins northwest of the Casmalia field, approaching the Point Sal positive area. Thin stringers of the upper Mohnian Santa Maria Valley type chert, type 1-A, appear in sections at Orcutt and West Cat Canyon.

The Luisian calcareous shale fractured zone, type 2 of the present classification, is well developed in the area of this section. The electric-log character of this zone is similar to the chert zone, with somewhat more subdued throws on the self-potential curve. Few isolated tests have been made of this zone.

Platy siliceous shale 200 feet above the chert zone, and described under type 3, has a somewhat permeable electric-log characteristic. This zone is productive in the Orcutt field, and reportedly produces a small amount of heavy oil in the Casmalia field.

The relatively simple stratigraphy and rather uniform distribution of fractured zones shown by the west-east section are in contrast to a more complex pattern exhibited by north-south diagrammatic sections.

Stratigraphic section BB' (Fig. 8) is the most westerly of the north-south sections, and extends from the west end of the Santa Maria field through the Casmalia field to the Lompoc field, a distance of 14 miles. The most northerly log, No. 1 on the section, is representative of a well developed chert section of the Santa Maria Valley type, or type 1-A. The chert is progressively overlapped toward the north by Pliocene Sisquoc. The second log on the south, No. 2, shows the same type of chert in the upper Mohnian 2.5 miles south of the Santa Maria Valley field. The lower Mohnian has not been penetrated in this area. The upper Mohnian type 1-A chert is replaced in the Casmalia field by moderately fractured,

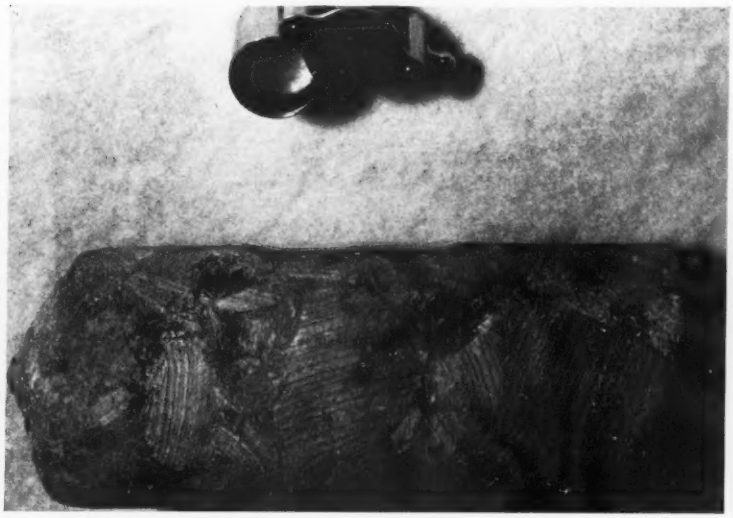


FIG. 3.—Type 1-A, Santa Maria Valley type chert (fractured).

FIG. 2.—Type 1-A, Santa Maria Valley type chert (unfractured).

FIG. 4.—Type 1-B, Cat Canyon type chert.

FIG. 5.—Type 1-B, siliceous limestone in Cat Canyon type chert.

FIG. 12.—Secondary quartz recovered by bailer from Cat Canyon well.

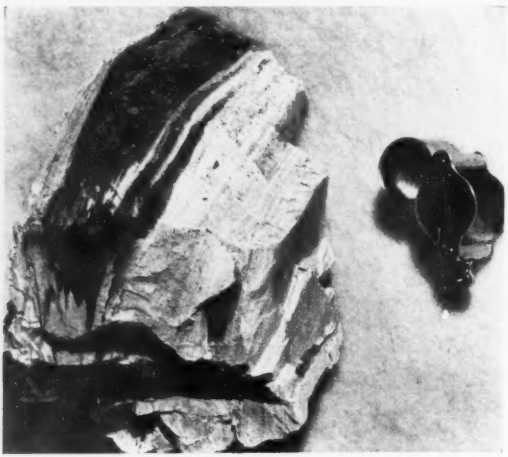


FIG 13.—Outcrop sample of type 1-B lower Mohnian chert.

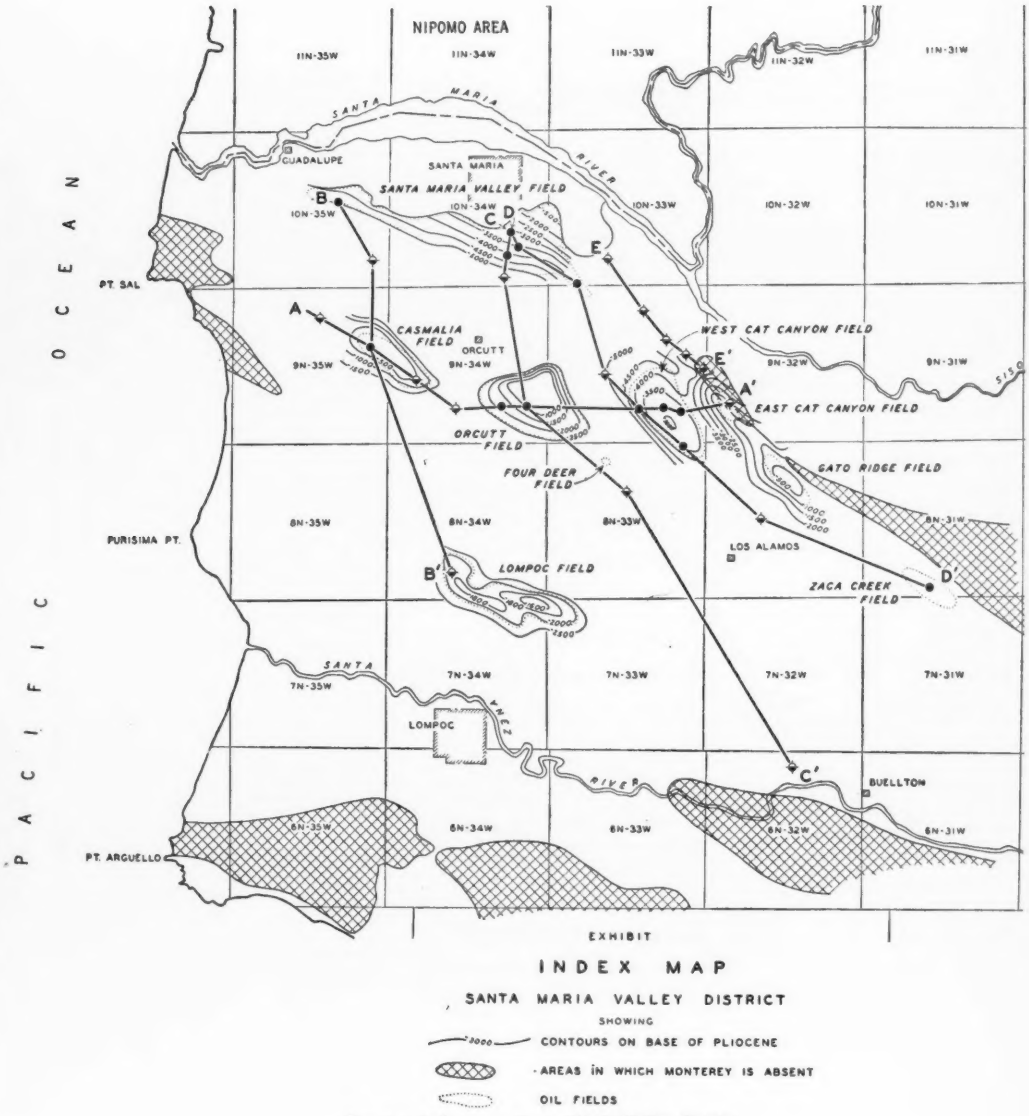
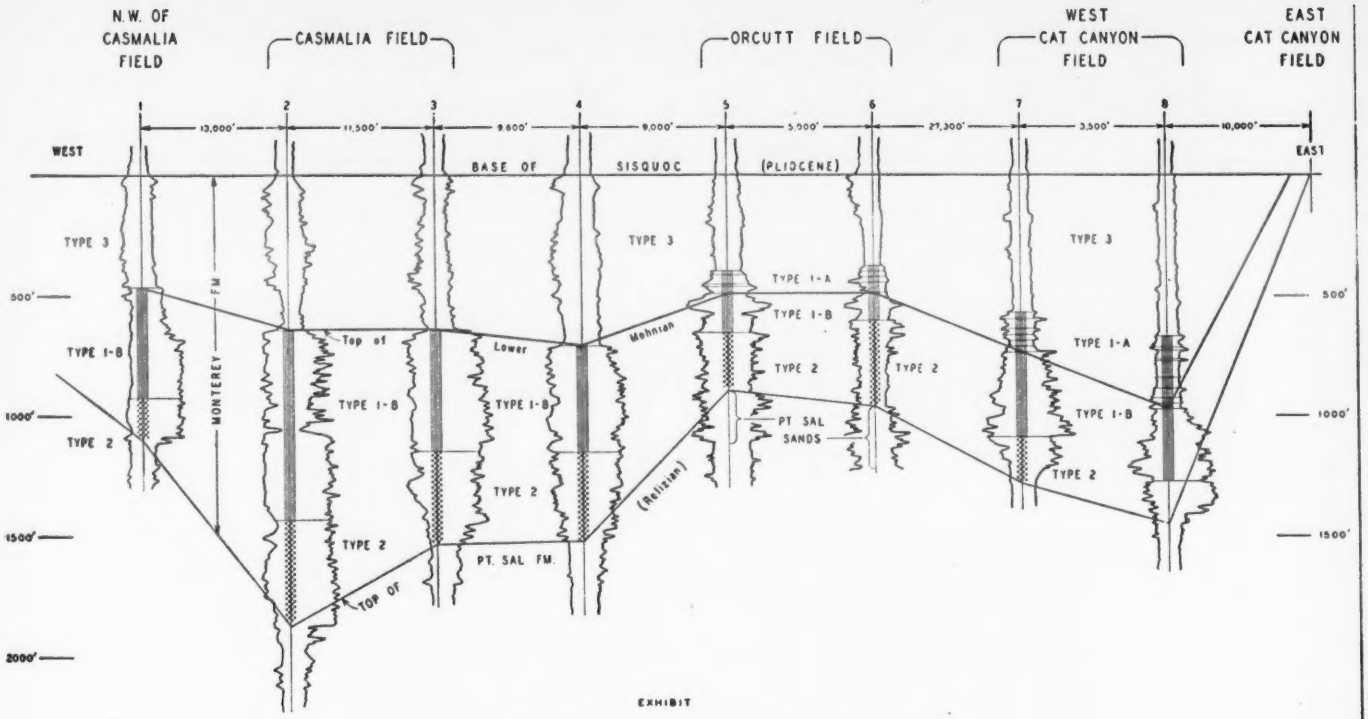


FIG. 6.—Index map, Santa Maria Valley district.



EXHIBIT

DIAGRAMMATIC SECTION A-A'

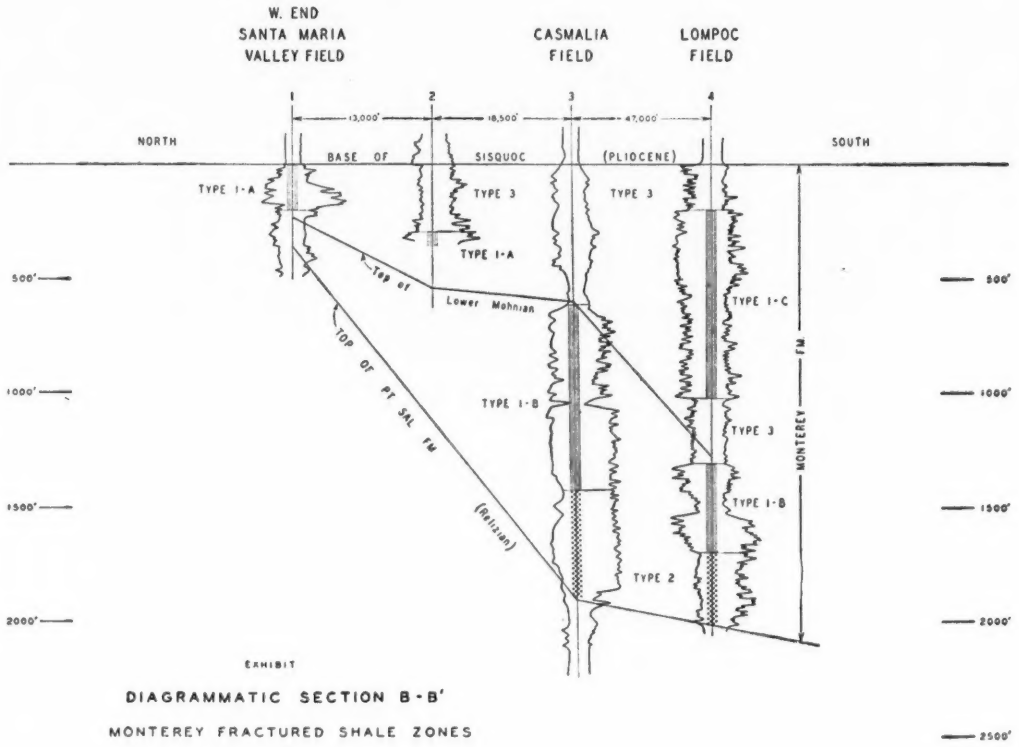
MONTEREY FRACTURED SHALE ZONES

TYPE 1 CHERT
- 1 A - SANTA MARIA VALLEY TYPE CHERT
- 1 B - CAT CANYON TYPE CHERT
- 1 C - LOMPOC TYPE CHERT

TYPE 2 LIMY SHALE (LUISIAN)

TYPE 3 PLATY SILICEOUS SHALE

FIG. 7.—Diagrammatic section *AA'*, Monterey fractured shale zones.



EXHIBIT

DIAGRAMMATIC SECTION B-B'

MONTEREY FRACTURED SHALE ZONES

TYPE 1 CHERT
1-A - SANTA MARIA VALLEY TYPE CHERT
1-B - CAT CANYON TYPE CHERT
1-C - LOMPOC TYPE CHERT
TYPE 2 LIMY SHALE (LUISIAN)
TYPE 3 PLATY SILICEOUS SHALE

FIG. 8.—Diagrammatic section *BB'*, Monterey fractured shale zones.

platy, thin-bedded brown shale. The well developed lower Mohnian Cat Canyon type of chert and Luisian calcareous shale of the Casmalia field are represented by a thin section of buff and brown siliceous shale and dark brown phosphatic shale at the west end of the Santa Maria Valley field.

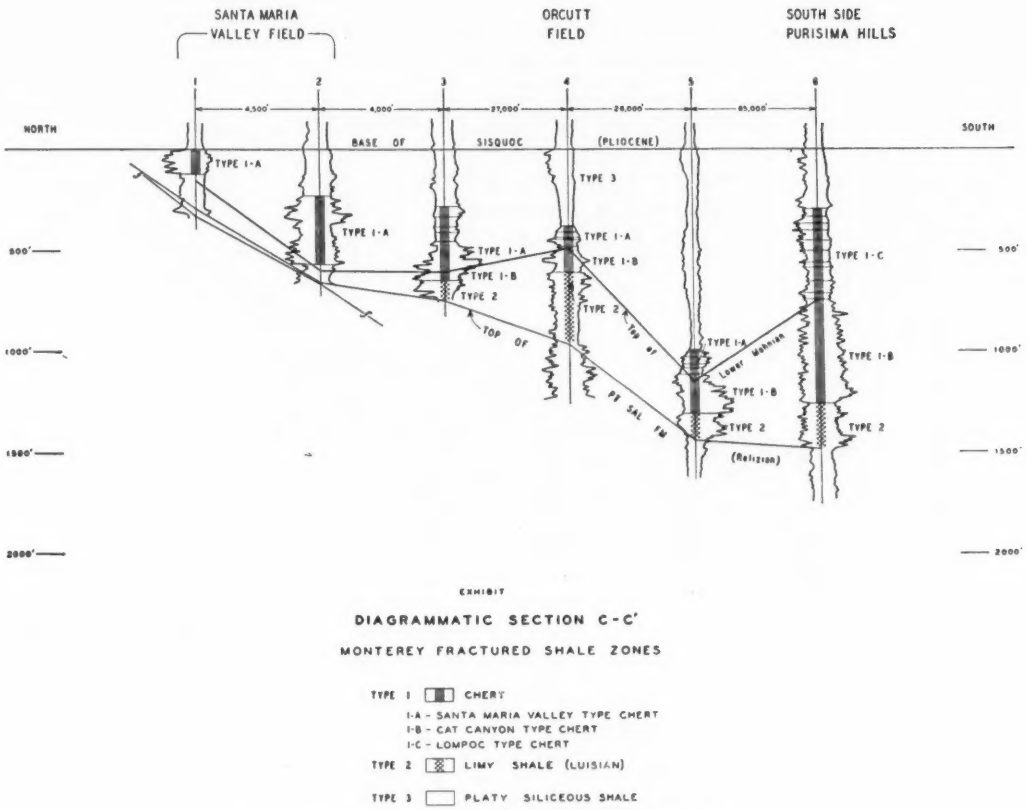
The upper Mohnian is cherty in the Lompoc field, but this section is the type described as 1-C above and is characterized by thin-bedded interbedded siliceous shale, siliceous limestone, and thin streaks of chert. This lithologic difference is reflected by the character of the electric logs in the Lompoc field.

The lower Mohnian Cat Canyon type of chert and Luisian calcareous shale are well developed in the Lompoc field. However, the only productive zones in the field are in the upper Mohnian chert, and the lower fractured zones are wet at all structural positions.

Stratigraphic section *CC'* (Figure 9) extends from the Santa Maria Valley field through the Orcutt field, to the south side of the Purisima Hills, a distance of 23 miles. Two wells at the north end of the sections, Nos. 1 and 2, encountered thickly developed chert of the upper Mohnian Santa Maria Valley field type. The next well, No. 3, a southern outpost test of the field, illustrates that the upper Mohnian chert grades into siliceous shale, and has the first appearance of the lower Mohnian Cat Canyon type of chert. Luisian calcareous shale is also present. The Orcutt section is similar to the last described, but chert is very poorly developed in the upper Mohnian. Well No. 5, 3 miles southeast of the Orcutt field, encountered a similar section, but with a thicker development of the Cat Canyon type chert. The Monterey on the south side of the Purisima Hills is similar to the Lompoc section (Fig. 8), but differs in that the upper Mohnian Lompoc type chert is very poorly developed and has been replaced by platy siliceous shale. The most interesting feature of the section is the clear evidence that the thick chert is younger from south to north.

Stratigraphic section *DD'* (Fig. 10) extends from the Santa Maria Valley field southeasterly through the West Cat Canyon field to the Zaca Creek field, a distance of 21 miles. On the north, two representative wells in the Santa Maria Valley field, Nos. 1 and 2, exhibit a thick development of upper Mohnian chert. The chert grades into platy shale southeast, and very little chert is present in the southeasterly outpost well No. 3. A few streaks of lower Mohnian type 1-B chert are present in this well. A large development of the lower Mohnian chert extends from the West Cat Canyon field southeast to the Zaca Creek field. The section in the well northwest of the West Cat Canyon field, No. 4, is not as cherty as in the Cat Canyon field. The upper Mohnian Santa Maria Valley type chert is represented by a few streaks in the Cat Canyon area, but is also thickly developed in the Zaca Creek field.

Stratigraphic section *EE'* (Fig. 11) extends from a well near the east end of the Nipomo positive area, southeast to the East Cat Canyon positive area, a distance of 6 miles. Well No. 1, near the east end of the Nipomo high, encountered



EXHIBIT

DIAGRAMMATIC SECTION C-C'

MONTEREY FRACTURED SHALE ZONES

TYPE 1 CHERT
1-A - SANTA MARIA VALLEY TYPE CHERT
1-B - CAT CANYON TYPE CHERT
1-C - LOMPOC TYPE CHERT
TYPE 2 LIMY SHALE (LUISIAN)
TYPE 3 PLATY SILICEOUS SHALE

FIG. 9.—Diagrammatic section *CC'*, Monterey fractured shale zones.

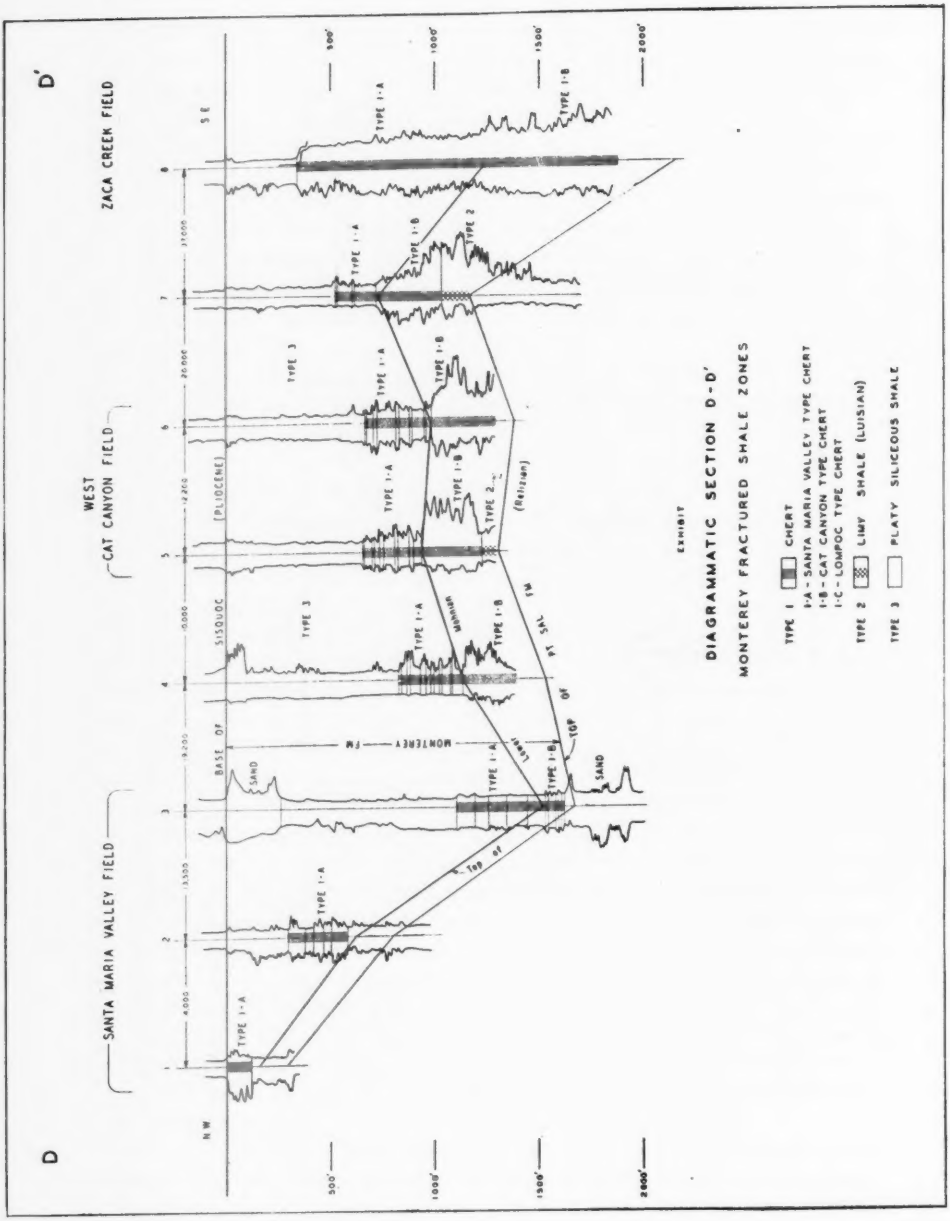


FIG. 10.—Diagrammatic section *DD'*, Monterey fractured shale zones.

FIG. 10.—Diagrammatic section *DD'*, Monterey fractured shale zones.

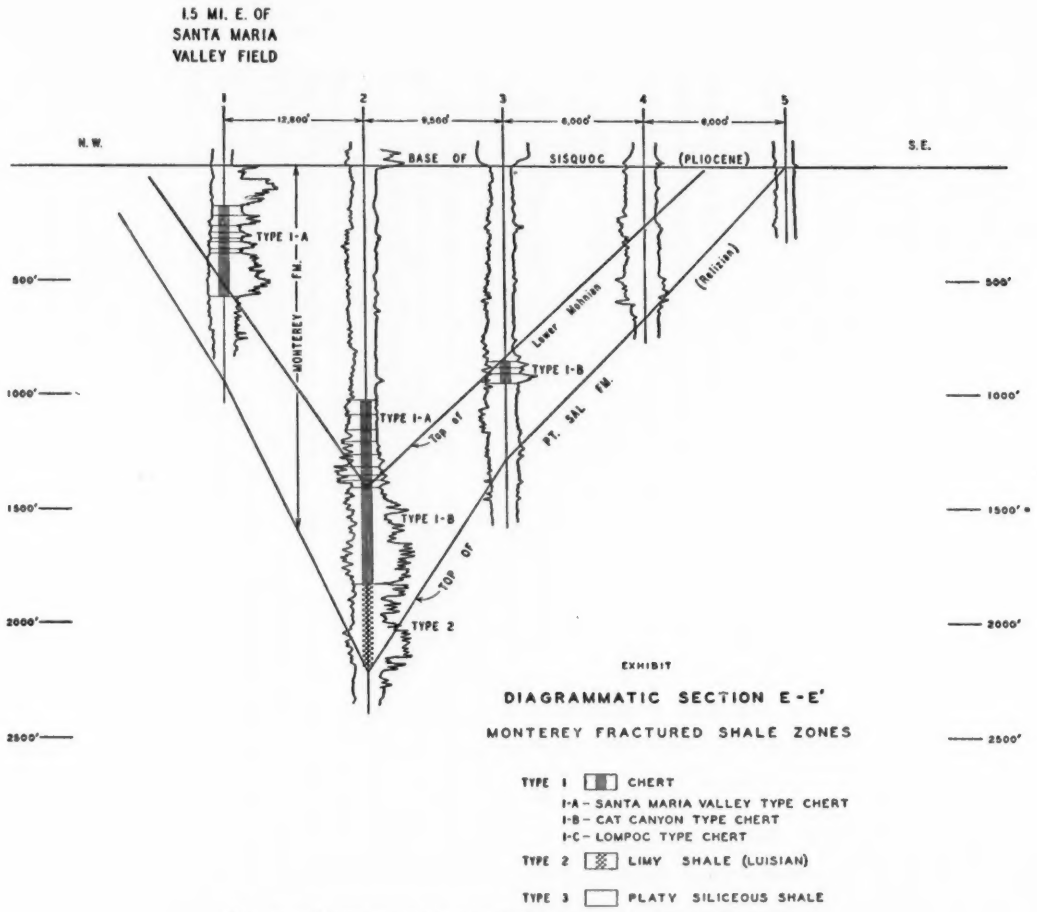


FIG. 11.—Diagrammatic section *EE'*, Monterey fractured shale zones.

a strongly developed chert section in the upper Mohnian. The very flat nature of the self-potential curve in this well may be caused by tar-sealed fractures rather than lack of fracturing. The Monterey thickens southeast to well No. 2. A few streaks of chert are in the upper Mohnian of this well, which encountered a very thick development of lower Mohnian chert of the Cat Canyon type and of Luisian fractured calcareous shale. Chert disappears on the southeast, although an equivalent section is present and chert is apparently replaced by relatively unfractured siliceous and diatomaceous strata.

The distribution of chert may be summarized as follows.

1. Lower Mohnian maximum development of chert is concentrated in two bands, one extending from the West Cat Canyon area southeast through the Gato Ridge and Zaca fields, the other extending from the Casmalia area southeast through the Lompoc field.

2. Upper Mohnian maximum development of chert is found throughout the length of the Santa Maria Valley field, except where overlapped, but is represented only by streaks downdip. Upper Mohnian chert is highly developed in the Zaca Creek area and the upper Mohnian is cherty in the Lompoc area.

Two apparent features of chert distribution may be postulated on the basis of the stratigraphic sections. These are as follows.

1. The maximum development of Mohnian chert apparently forms a band which in general parallels the margin of the Monterey basin, and chert development is meager in the deeper parts of the basin. Chert formation is also meager in what is probably a shoreward direction from the band of maximum chert.

2. The lower to upper Mohnian seas apparently transgressed northward on the Nipomo positive area. The sections indicate that this was accompanied by a northward transgression of maximum chert development.

Chert appears to be a facies in the same sense as sand, shale, and limestone on the basis of these two postulates. There appears to have been a definite environment in which the elements necessary for chert were deposited, while they were not deposited elsewhere in the basin. The original material may or may not have resembled the present consolidated rock. There is abundant evidence of secondary redistribution of silica and chert in both outcrops and cores. Two clear examples of secondary movement of silica within chert bodies are here mentioned.

1. Secondary quartz, illustrated in Figure 12, occurring in excellent crystals about $\frac{1}{4}$-inch in diameter, has recently been recovered with a bailer during remedial work on a structurally low well at West Cat Canyon. Similar material was found in ditch samples while the well was being drilled. The quartz was recovered from a 20-foot zone 65 feet below the top of the lower Mohnian.

2. Figure 13 illustrates a sample of lower Mohnian cherty shale from an outcrop in the vicinity of Los Berros Creek in the Nipomo area. The bulk of the sample is composed of white opaline chert and porcellaneous shale, which is cut by lenses and veinlets of brown opaline chert.

There are no clear examples in the Santa Maria district where chert is well

developed and is not sufficiently fractured to possess some porosity and permeability. Some fractures may have been sealed by tar where cherty sections have not yielded fluid on tests. Fractured zones are probably the result of adjustments in brittle rocks to tectonic movements. Theoretically, highly fractured areas should be related to structural features, such as anticlinal axes or faults. No such relationship can be demonstrated in the Santa Maria district at present. It appears that rocks sufficiently brittle to be susceptible to fracturing are regionally fractured and broken and are potential reservoirs. Variations in fracturing and in consequent size of wells are extreme and unpredictable locally in Santa Maria oil fields. A property in the southeast part of the Santa Maria Valley field is an example of this. The property is drilled with one well to 10 acres. Initial production of these wells varied from the maximum of 2,500 barrels per day to the minimum of 90 barrels per day. Cumulative production of the wells varies between the minimum of 12,000 barrels to the maximum of 500,000 barrels. A direct offset well to the property is reported to have produced more than a million barrels and is still believed capable of producing 1,200 barrels per day. These figures may be somewhat misleading because wells were not completed at the same time, but they are believed to reflect a great variation in fracturing in the chert zone.

Initial production rates of 2,500 barrels per day were common, and potentials as high as 10,000 barrels per day were established in the early history of the Santa Maria Valley field. These high rates of production of heavy viscous oil indicate high permeability. An estimated maximum permeability of 35 darcys and an average permeability of 10–15 darcys have been obtained empirically for the chert zone of the Santa Maria Valley field by comparison with oil sand zones in various California oil fields. The estimates are based on potentials of oil sands of known permeability in zones where thickness and pressure are similar to the Santa Maria Valley field. Santa Maria crude is much more viscous than the oil produced from sands used for comparison. The permeability of sands used for comparison is a maximum of 2–3 darcys. The much higher estimated permeability of the chert zone is the result of adjusting the permeability of comparable sand zones to fit the viscosity of Santa Maria Valley field crude at bottom-hole temperatures. Similar but somewhat smaller values for the permeability of fractured chert have been obtained from productivity indices by the method described by Norris Johnston.[5] The permeability of sands and fractured reservoirs are not strictly comparable because of physical characters such as surface tension and capillary action, but it seems clear that the permeability of fractured chert is generally high and in some places extreme.

Two outstanding effects of the high permeability are the following.

1. The production of a well is commonly influenced by an offset well. In some places, fluid lost in a well is produced by offset wells. In one well a casing failure

[5] Norris Johnston and John Sherborne, "Permeability as Related to Productivity Index," *A.P.I. Drilling and Production Practice* (1943).

developed, giving fresh water access to the chert zone. Water cuts in an adjacent well reflected the condition immediately.

2. A common development of a very unequal encroachment of edge water. Two outstanding examples of this condition are the present irregular oil-water interfaces along the south-central part of the Santa Maria field, and at the northwest end of the West Cat Canyon field.

A well developed fractured chert zone may ultimately produce 20,000–40,000 barrels per acre or approximately 100–150 barrels per acre foot. It has been estimated that producible oil in the chert zone may be as high as 30 per cent of the total oil in the formation. The average porosity of such a zone is 6 per cent on the basis of these figures.

Fractured rocks form satisfactory reservoirs for oil of heavy to very heavy gravity because of the high permeabilities and because sand problems characteristic of low-gravity oil sands are not encountered. It seems probable that lighter crudes could be produced commercially from zones exhibiting less fracturing.

KNOXVILLE PRODUCTION

The basement production of the Santa Maria Valley field was discovered in December, 1942, by W. R. Gerard's Acquistapace well No. 1 which initially flowed 1,200 barrels per day of 18.5° gravity oil. This well was in an area considered sub-commercial in Monterey zones. It encountered 250 feet of Monterey, with 120 feet of cherty shale below the Sisquoc. Approximately 30 feet of detrital or weathered material was found at the top of the Knoxville, and 90 feet of Knoxville fractured sandstones were penetrated. The oil in the Knoxville is identical with Monterey oil and is believed to have migrated from the Monterey into fractured members of the older formation.

Both the Monterey and older rocks are open to production in the discovery well and in most wells penetrating the Knoxville. Therefore, it is difficult to evaluate the extent of basement production because of the lack of selective tests. Wells which produce from the Knoxville include (1) wells drilled north of the Monterey limits and productive from Knoxville alone, (2) wells deepened into the Knoxville with an increased productivity, and (3) wells completed in both Monterey and Knoxville with production greatly in excess of rates expected from Monterey alone. Wells which prove the Knoxville non-productive include (1) wells north of Monterey limits which lack fluid in the Knoxville, (2) wells lacking fluid in both Knoxville and Monterey, (3) wells deepened into the Knoxville without change in productivity, and (4) wells penetrating both Knoxville and Monterey with production rate similar to Monterey zones.

Figure 14 is a generalized structure map of the Santa Maria Valley field, contoured on top of the Knoxville and showing locations of productive and non-productive wells. Productive Knoxville wells are limited to the north-central part of the field. The west end of the field is not favorable for basement production because the oil-water interface common to both formations occurs within the

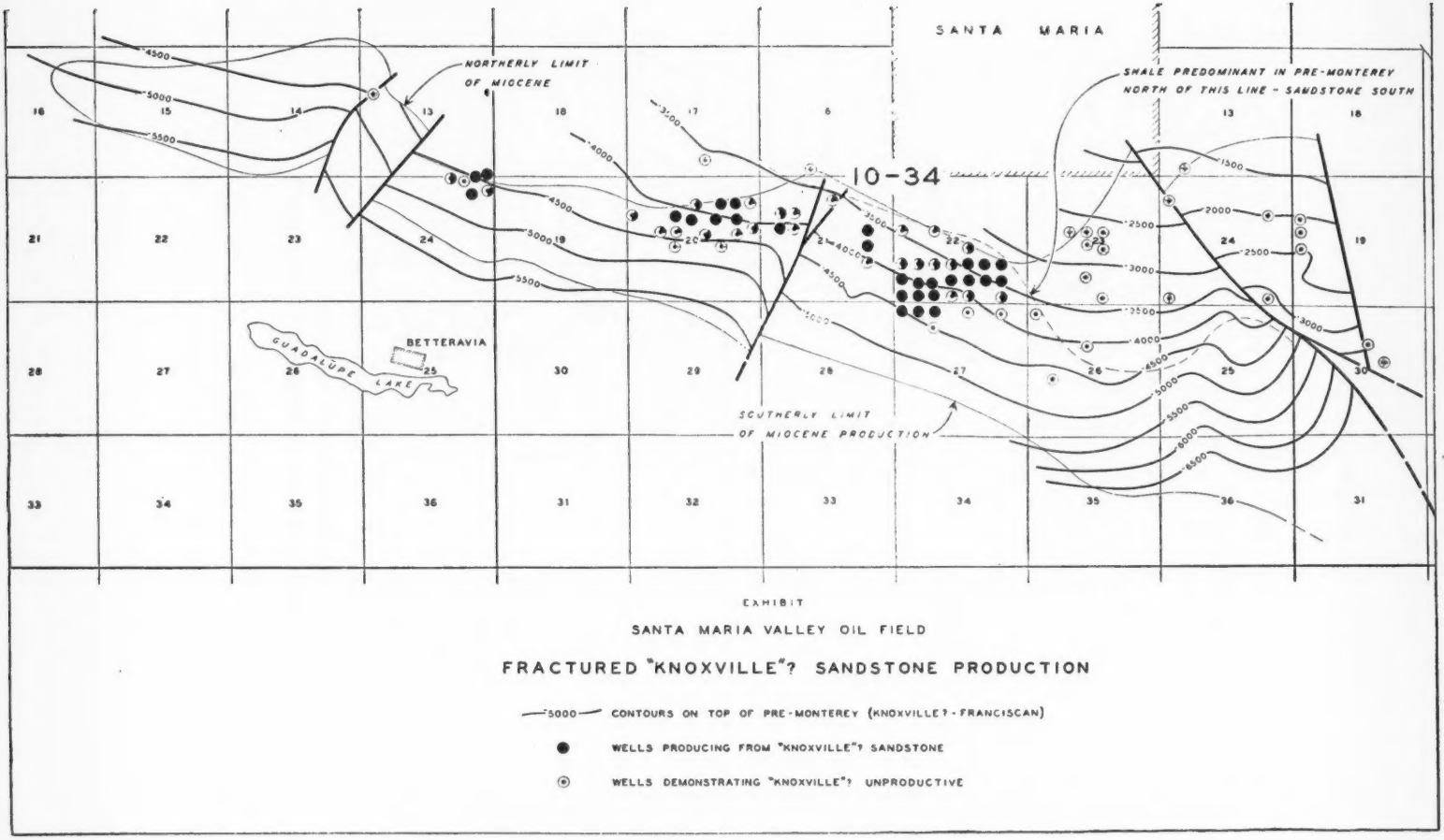

SANTA MARIA
NORTHERLY LIMIT OF MIOCENE
SHALE PREDOMINANT IN PRE-MONTEREY NORTH OF THIS LINE - SANDSTONE SOUTH
10-34
BETTERAVIA
GUADALUPE LAKE
SOUTHERLY LIMIT OF MIOCENE PRODUCTION
EXHIBIT
SANTA MARIA VALLEY OIL FIELD
FRACTURED "KNOXVILLE"? SANDSTONE PRODUCTION
—5000— CONTOURS ON TOP OF PRE-MONTEREY (KNOXVILLE? - FRANCISCAN)
WELLS PRODUCING FROM "KNOXVILLE"? SANDSTONE
WELLS DEMONSTRATING "KNOXVILLE"? UNPRODUCTIVE

FIG. 14.—Santa Maria Valley oil field, fractured Knoxville sandstone production.

EXHIBIT

TYPICAL ELECTRIC LOG
OF
"KNOXVILLE" PRODUCTIVE WELL

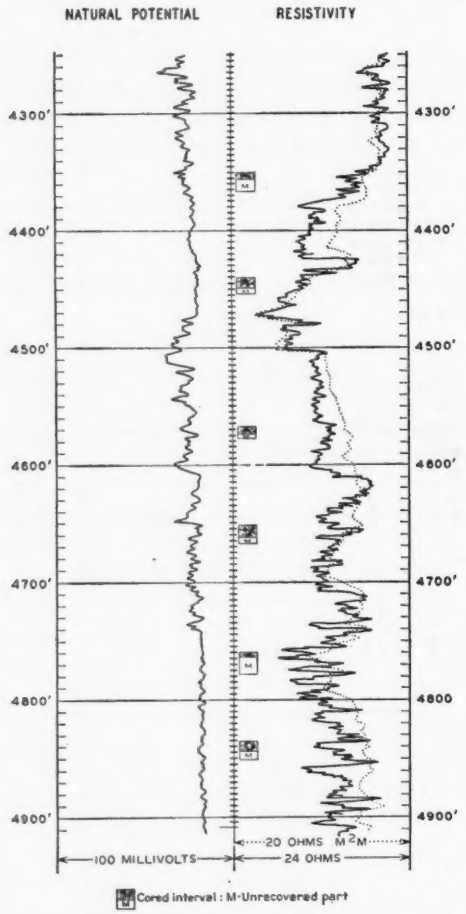


FIG. 15.—Typical electric log of Knoxville productive well.

Monterey. Some wells have found the Knoxville non-productive at the east end of the field. These wells encountered mainly gray and black, micromicaceous, slickensided, plastic-appearing shale, apparently without reservoir characteristics, while productive wells encountered dominantly sandstone. Casts of the megafossil *Aucella* have been reported in the shales at the east end of the field, and on the basis of these the zone is referred to as the Knoxville. No fossils have been reported in the productive area. The approximate northern limit of fractured Knoxville sandstone is indicated on the map. The northern limit of production is believed to be controlled partly by overlap of the fractured sandstone by the Sisquoc, and partly by tar seal, at the contact.

Figure 15 is a typical electric log of a well producing from the Knoxville, showing the section penetrated below the Miocene. The well was originally completed in the Monterey in August, 1942, initially producing 25 barrels per day. In its original condition, the total depth was 4,332 feet after penetrating 90 feet into the Knoxville. The liner was landed at 4,234 feet or at the top of the basement without a bottom plug. The last production before deepening was 13 barrels per day. The well was deepened to 4,910 feet, equivalent to 665 feet of penetration into the Knoxville, and was recompleted December 3, 1945, pumping 220 barrels per day of 17.1° gravity clean oil. Present production of the well is 90 barrels per day, and it has produced a cumulative production of approximately 70,000 barrels of oil from the Knoxville. Cores and ditch samples indicate the well encountered dominantly sandstone. The sandstone is light blue-gray, medium- to fine-grained, micaceous, pyritiferous, very calcareous, with veinlets of calcite. Fractures were present in most of the cores, spaced from a few inches to 3 feet apart, with a coating of oil on the fracture surfaces. The sandstone was generally oil-stained in a width of $\frac{1}{4}$–$\frac{1}{2}$ inch from the fractures. Live oil was present in cores throughout the interval, but the gravity of the oil appeared to increase with deeper penetration.

SUMMARY

It appears that the brittle hard rocks of the Santa Maria district are regionally fractured, but show extreme local variation in amount of fracturing. Chert is the most important fractured rock, but calcareous shale, platy siliceous shale, and sandstone are sufficiently fractured to form commercial oil reservoirs. The main zones susceptible to fracturing have wide distribution in the district. The distribution of maximum chert development suggests that the chert originated as a sedimentary facies. Fractured chert reservoirs are characterized by low porosity and high permeability. Expected recovery per acre foot in such zones is relatively low.

A knowledge of the characteristics of fractured rock reservoirs, observed in the course of drilling, is an aid to the evaluation of the productive possibilities of such a reservoir; but in the final analysis production tests are required.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 1 (JANUARY, 1949), PP. 52-72, 11 FIGS.

LYONS SANDSTONE OF COLORADO FRONT RANGE*

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ABSTRACT

The unique original structures of the Permian Lyons sandstone of the Front Range of Colorado are described in detail. A chart, two line diagrams and several photographs set forth the salient aspects of the formation; hence, the paper is primarily a study in sedimentation. Certain original structures in the Lyons such as cross-stratification, lamination, and rhomboid ripple mark are compared with similar features of modern beaches. These facts and inferences combined with the stratigraphic relationships of the Lyons lead to the conclusion that the Lyons sandstone is an ancient littoral deposit in which both shore and eolian processes are discerned.

A secondary conclusion is that the Lyons is Middle Permian in age, approximately equivalent to the Leonard formation of West Texas.

INTRODUCTION

The Lyons sandstone of the Front Range of Colorado was named and described by N. M. Fenneman[1] in 1905. He designated the quarries near the town of Lyons the type locality. Fenneman's definition includes all those strata between the Fountain arkose below and

a series of sandstones and sandy shales, with a little limestone,

the Lykins series, above. Significant parts of Fenneman's[1] original description follow.

Above these massive beds and more or less arkose sandstone (Fountain formation) are other beds of purely quartzose sandstone . . . . The long washing and complete assortment which these sands underwent on the shore of the early sea was attended by cross-bedding of unusual dimension and perfection.

Tieje[2] challenges Fenneman's shore hypothesis origin of the Lyons sandstone and follows the earlier lead of Vail[3] who concludes that the Lyons is dominated by sediments of eolian origin, admixed with stream sediments. Heaton[4] without offering evidence suggests that the cross-bedding of the Lyons indicates a near shore deposit.

* Read in part before the Association at Los Angeles, March, 1937, and Chicago, April, 1940. Manuscript received, September 25, 1948.

** Professor of geology and assistant head of the department, University of Colorado. Petrographic data on the Lyons sandstone came from the thesis work of J. M. Maxwell, done as a part of the requirement for the Master's degree at the University of Colorado. J. M. Kirby, who is co-author of Figure 2, contributed helpful suggestions regarding correlation. The following have assisted with the measurement of sections in the field: R. D. Sample, H. W. Osborne, Julian Low, L. O. Quam, and J. E. Simmons. W. C. Toepelman read the manuscript.

[1] N. M. Fenneman, "Geology of the Boulder District, Colorado," *U. S. Geol. Survey Bull. 265* (1905), p. 23.

[2] A. J. Tieje, "The Red Beds of the Front Range in Colorado," *Jour. Geol.*, Vol. 31 (1923), pp. 192–207.

[3] C. E. Vail, "Lithologic Evidence of Climatic Pulsations," *Science*, New Ser., Vol. 46, No. 1178 (1917), pp. 90–93.

[4] Ross L. Heaton, "Ancestral Rockies and Mesozoic and Late Paleozoic Stratigraphy of the Rocky Mountain Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 2 (1933), p. 149.

Henderson[5] is non-committal regarding the origin of the Lyons, though he indicates, following Vail, that part of the Lyons is subaerial.

Lee[6] redefines the Lyons formation by proposing that the Lyons sandstone be limited

> to the cross-bedded upper part, to which the original description chiefly applies.

Part of the sediments included in Fenneman's original description are referred by Lee to the underlying Ingleside formation of Butters.[7]

Lee's[8] contention that the name Lyons should be limited to those sandstones characterized by conspicuous cross-bedding is tenable, but the application of this definition to the "Creamy sandstone" of the Denver basin introduces additional confusion. He states:

> These beds (the Creamy sandstone) cannot be the same as the Lyons sandstone of the type locality.

Lee's view is that the Lyons sandstone of the type locality thins and disappears south of Eldorado Springs, Colorado, whereas, actually, these strata can be traced laterally into the "Creamy sandstone" in the area just south and west of Ralston Peak (Sec. 31, T. 2 S., R. 70 W.).

The correlation of the "Creamy sandstone" with the Lyons of the type locality ultimately permits an acceptable explanation of the puzzling relationships of the Lyons with adjacent strata.

The present paper sets forth in detail: (1) the characteristics of the Lyons sandstone; (2) an interpretation of these characteristics; (3) an explanation of the complex relations of the Lyons sandstone with adjacent formations in the light of the interpretation; and (4) the age and regional correlation of the Lyons sandstone.

AREAL DISTRIBUTION

The Lyons sandstone crops out almost continuously along the east side of the Front Range of Colorado from T. 12 N., R. 70 W. in northeast Larimer County, near the north line of the state, southward to a place southeast of Sedalia, Colorado in T. 7 S., R. 68 W. From here southward to Red Canyon in T. 17 S., R. 67 W., in the southwest corner of El Paso County, outcrops are discontinuous.

From a short distance southwest of Sedalia, southward to Perry Park (T. 9 S., R. 68 W.) and from Perry Park southward to Colorado Springs (T. 14 S., R. 67 W.), exposures are few and poor. This condition also prevails south of Colorado Springs to a place west of Fountain, Colorado (T. 16 S., R. 67 W.). In these areas

[5] Junius Henderson, "Foothills Formations of North-Central Colorado," *Colorado Geol. Survey Bull. 19* (1920), p. 90.

[6] W. T. Lee, "Correlation of Geologic Formations between East-Central Colorado, Central Wyoming and Southern Montana," *U. S. Geol. Survey Prof. Paper 149* (1927), p. 12.

[7] R. M. Butters, "Permian or 'Permo-Carboniferous' of the Eastern Foothills in Colorado," *Colorado Geol. Survey Bull. 5*, Pt. 2 (1913), pp. 61–94.

[8] Lee, *op. cit.*, p. 5.

the outcrop either is faulted out or is buried by unconformable Dawson arkose of Eocene age. Southward from T. 16 S., R. 67 W., the Lyons is traceable to Red Canyon (T. 17 S., R. 67 W.), but is not recognized in the belt of Paleozoic strata which crop out south of Red Canyon. The paucity of continuous good exposure in the southern part of the area probably does not seriously impair the investigation, as controversial parts of the formation are well exposed.

How far eastward into the Denver basin the Lyons sandstone extends is unknown. A few wells on the west flank of the basin penetrate sandstone which occupies the stratigraphic position of the Lyons. Other wells on the east flank of the basin in eastern Colorado log sandstones of appropriate stratigraphic position and texture for correlation with the Lyons of the outcrop. Inasmuch as one of the chief bases of recognition of the Lyons is the distinctive cross-bedding, positive correlation with well cuttings is not attempted.

THICKNESS

The Lyons sandstone is approximately 370 feet thick at the type locality. This thickness is measured from the lowermost recognizable, Lyons-like structure below, to the red siltstones in the Lykins and its equivalents, above. Numerous arkose lenses which thread the Lyons are included in the thickness. Changes in thickness are recorded in the chart (Fig. 2). In general the Lyons becomes progressively thinner northward.

COMPOSITION

Typical Lyons sandstone is composed of more than 99 per cent subangular grains of quartz. Rounded grains of magnetite, garnet, and zircon appear in some specimens. Most specimens contain rounded pellets of limonite and hematite.

In the area between Ralston Creek and Red Canyon, much feldspar and some rounded fragments of muscovite are interstratified, especially near contacts with adjacent formations. From Lyons to the north boundary of Colorado few lenses of arkosic sandstone crop out, excepting near the base of the formation.

TEXTURE

Internal structure.—Typical Lyons sandstone is made up of single grains of quartz held together by calcareous, ferrugenous and siliceous cementing materials. An intraformational conglomerate composed of fragments of a sandstone closely resembling the Lyons sandstone on which this conglomerate rests, crops out on the north bank of South St. Vrain Creek, a mile southwest of Lyons.

South of Morrison, Colorado, at Turkey Creek fragments of gypsum, many of them showing considerable attrition, are embedded in the top of the Lyons sandstone.

Grain size.—Mechanical analysis of 50 typical samples of Lyons sandstone shows that the materials fall into five groups. Fifty per cent by weight is fine sand ($\frac{1}{4}$–$\frac{1}{8}$ mm.); 25.5 per cent is medium sand ($\frac{1}{2}$–$\frac{1}{4}$ mm.); 22 per cent is very fine sand

($\frac{1}{8}$—$\frac{1}{16}$ mm.); 2 per cent is silt and clay (less than $\frac{1}{16}$ mm.); and approximately $\frac{1}{2}$ per cent is coarse sand (1–$\frac{1}{2}$ mm.). Grains in excess of 1 mm. in diameter are seen rarely.

Following Payne[9] the Lyons is classed as a fair to well sorted sand inasmuch as 97.5 per cent of the formation falls into three size groups. Inspection of many samples discloses considerable contrast in grain size between adjacent laminae whereas grain size in single laminae is uniform. Hence, sorting is more highly developed than is indicated by the average figures here given.

Grain shape.—Lyons sandstone grains are dominantly equi-dimensional. Most grains are spheroidal, oblate spheroidal, or prolate spheroidal in terms of the shape classification diagram of Payne.

Grain roundness.—75–80 per cent of Lyons sandstone grains are subangular. Some are angular and some subrounded. In terms of Krumbein's image diagram recently reviewed by Payne,[10] the bulk of Lyons sandstone grains are in roundness class .3; with considerable numbers of grains in roundness classes .2 and .4. Spherical or nearly spherical grains, rare in general, are found in some places.

Grain surface texture.—Maxwell's investigation of 5,000 grains from various samples of Lyons sandstone, discloses that approximately 52 per cent of the grains display a frosted or matte surface, whereas the remaining 48 per cent exhibit a bright glassy surface.

ORIGINAL STRUCTURES

Lamination and cross-lamination.—Lamination in the Lyons sandstone is an extremely persistent characteristic. Most laminae range in thickness from no more than $\frac{1}{2}$ mm. (the thickness of single grains) up to 50 or 60 mm. Single laminae in many places may be traced 30–50 feet laterally, but in other places this continuity is interrupted by the lack of parallelism in angle of dip of laminae. Hence, truncating surfaces which transect underlying laminae act as the floor of deposition for overlying laminae and this overlying set in turn is transected by the next overlying. Figure 3 portrays this structure. In most places the lack of parallelism is the result of changes in the angle rather than the direction of dip of laminae; in other words, there is a decided tendency toward parallelism of strike within groups of adjacent laminae.

Within the vertical limits of a single lamina, grain size is remarkably uniform. Many adjacent laminae likewise contain grains of equal size; but in many others an abrupt change in grain size from lamina to lamina is discerned.

In most places adjacent laminae disclose slight changes in color resulting from different degrees of staining by iron oxide. This color is clearly a stain on the grains which may be removed by boiling grains with hydrochloric acid. In many places this iron oxide stain is not uniformly distributed, and hence imparts a mottled appearance to the outcrop.

[9] Thomas G. Payne, "Stratigraphical Analysis and Environmental Reconstruction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 11 (November, 1942), p. 1707, Fig. 3.

[10] Payne, *op. cit.* Fig. 4, p. 1712.

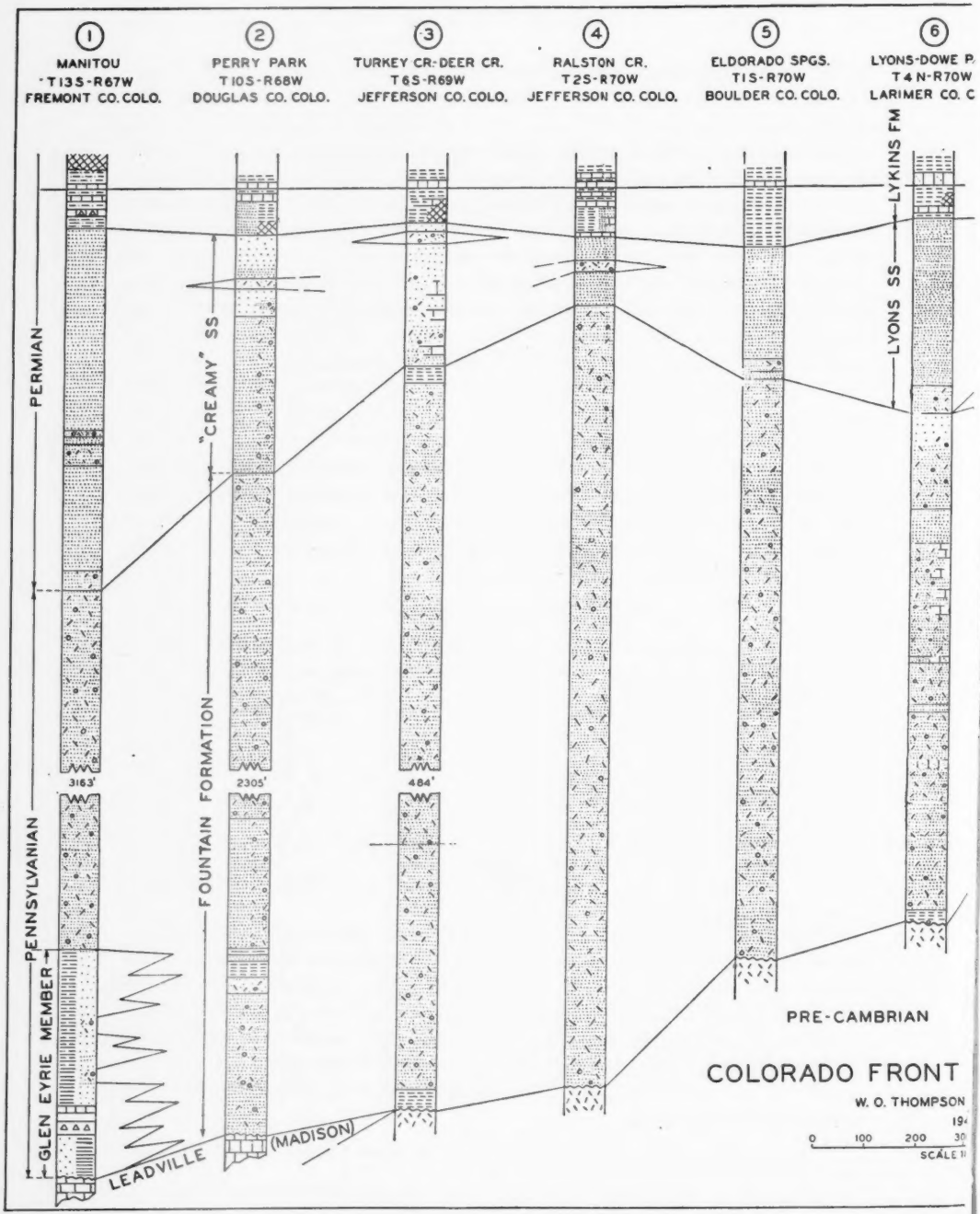
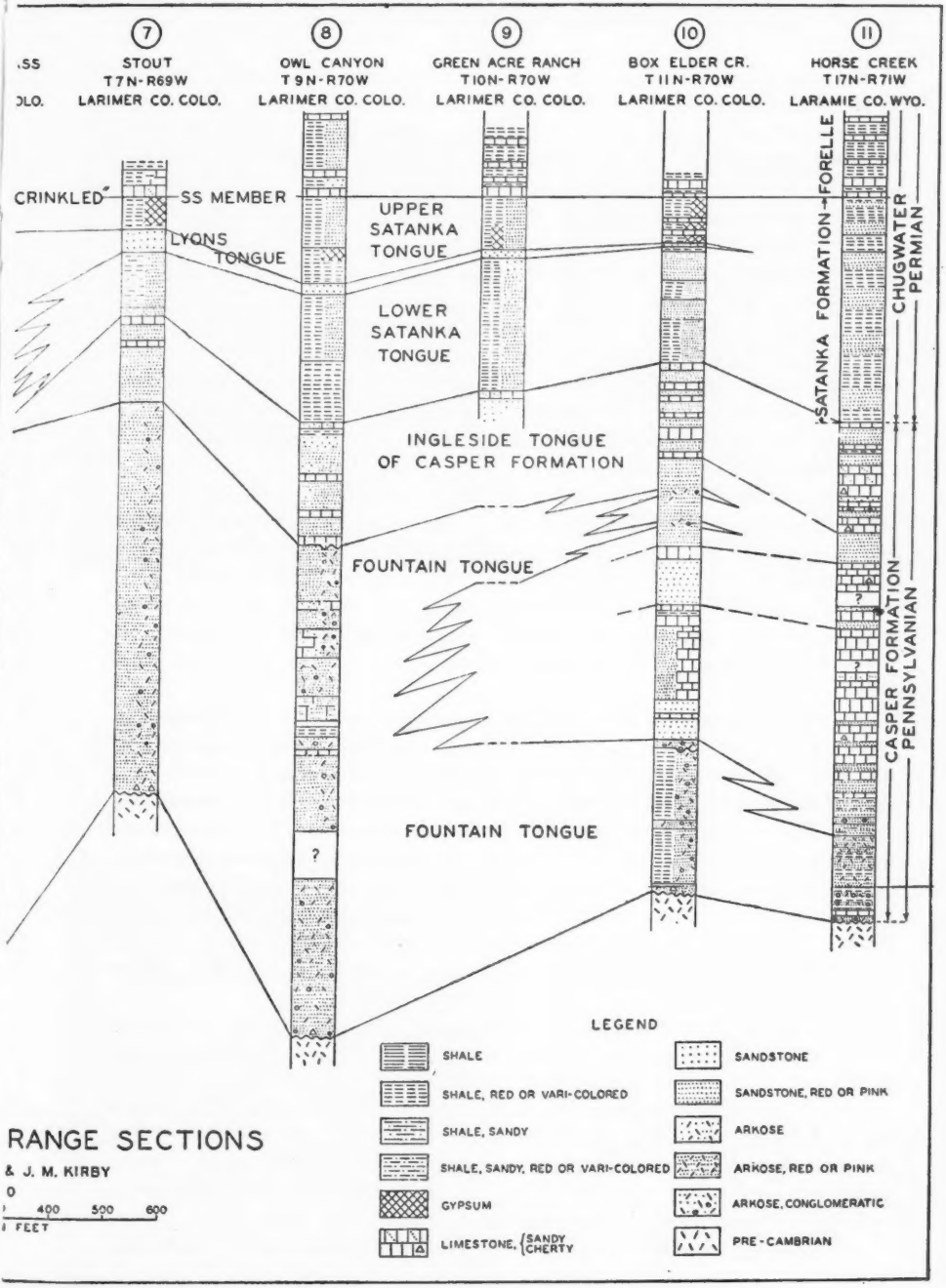


FIG. 2.—Colorado Front



Range sections.

Cross-stratification.—The term "cross-stratification" applies to lack of parallelism in major groups of laminae, each of which is cross-laminated within. The cross-stratification is grouped into three major types, designated here: diastemic omission and overlap, overlapping scoop-like embayments, and buried channels.

Diastemic omission and overlap.—The type of cross-stratification designated diastemic omission and overlap results from the combination of groups of cross laminated strata tens of feet thick with almost plane surfaces many hundreds of square feet in area. These surfaces transect strata below and act as the floor of deposition for overlying strata. One such surface in the quarries north of Lyons may be traced more than 1,500 feet in a northerly direction along the general trend of the outcrop and for at least 500 feet laterally within the quarries (Fig. 4). Several major surfaces are discerned on abundant fresh rock surfaces in these quarries. All these major surfaces seem to have a low eastward component of dip, though none are exactly parallel.

Each major surface results from the multiple intersection of several uniform planes of slightly different strike and dip. At the intersection of two such planes a low straight ridge results. The courses of these ridges vary with the angle and direction of dip of the involved planes. Figure 5 illustrates this relationship. Each major surface thus results from the merging of several nearly, but not quite parallel, planes. The product is a widespread undulating surface, the fractional parts of which are planes or near planes which appear as facets on the main surfaces.

In the Lyons quarries three such major surfaces are discerned. Transection of one surface by another discloses the fact that they become progressively younger from west to east. The surface designated *C* in Figure 6 diagram transects *B* and is, in turn, transected by *D*. At each place of meeting the transecting surface dips more steeply eastward than the surface transected. This arrangement delineates two large wedges of laminated and cross-laminated sediments which are designated *E* and *F* in the diagram. These wedges thin to nothing eastward but increase in thickness westward. They are composed of groups of laminae with a westward or southwestward component of dip. The westward-dipping laminae bury eastward-dipping major surfaces and are themselves truncated above by other major surfaces.

The laminae of westward dip are essentially parallel in strike and in direction of dip, though the angle of dip varies abruptly in some places. This relative uniformity of attitude in westward-dipping laminae is in sharp contrast with the extremely intricate cross-lamination of the eastward-dipping strata which overlie the major surfaces that truncate the westward-dipping laminae (Fig. 7). The major surface thus transects the underlying laminae and serves as the floor of deposition for those overlying. The change in grain size across such major breaks is no greater than the change from lamina to lamina.

Overlapping scoop-like embayments.—The truncating surfaces described in the

FIG. 1.—Typical Lyons sandstone on Dry Creek southwest of Loveland, Colorado.

FIG. 3.—Lamination and cross-lamination in Lyons sandstone.

FIG. 4.—Extensive surface in quarry at Lyons.

FIG. 5.—Low ridges formed by nearly parallel transecting surfaces.

FIG. 7.—Westward-dipping laminae truncated and overlain by eastward-dipping laminae.

FIG. 8.—Scoop-like embayment of truncating surface.

FIG. 9.—Rhomboid ripple mark on Lyons sandstone slab.

FIG. 10.—Bubble impressions or rain prints.

previous paragraph though extensive, are not simple planes. In addition to the ridges here described (Fig. 5), these surfaces are scalloped in places by well defined scoop-like embayments which plunge eastward (Figs. 4 and 8). These embayments are separated by low east-plunging ridges which in shape and dimension resemble beach cusps. The embayments are filled with cross-laminated sediment. Many such embayments appear to have formed but most of them are partly or completely destroyed by the depositing agent before becoming a permanent part of the sandstone. Later new embayments form, with axes that do not lie in the same place as the earlier ones; hence, undestroyed laminae of the earlier embayment are truncated by the surface which is the floor of a new embayment. This surface is later buried by laminae that develop in the new embayment. This overlapping of the laminated sediments results in a type of cross-stratification which Knight[11] designates "Festoon cross-bedding."

Buried channels.—In many places lenticular courses of crudely sorted arkose and conglomerate are within the main body of the Lyons. These bodies rest in a relatively narrow channel which is cut out of typical Lyons sandstone. The contact between the arkose and Lyons sandstone is very sharp. Floors of channels are concave upward (Figures 6 and 11).

Swash marks.—Minute, arcuate, thread-like ridges of sand appear in places on bedding surfaces of the Lyons sandstone. These ridges in most places are less than $\frac{1}{16}$ inch high and of the same width. They seldom can be traced for more than 3 or 4 feet before being obliterated by other similar ridges, formed later and with slightly different trend. Their occurrence seems limited to bedding surfaces with an original eastward component of dip. The succession of obliteration is such that the forming agent must have retreated eastward.

These original structures closely resemble the original structures of modern beaches variously described as "swash mark" by Twenhofel[12] and as "wave marks" by Kindle.[13]

Rhomboid ripple mark.—Sand patterns that resemble the scales of a ganoid fish are on numerous bedding surfaces of the Lyons sandstone (Fig. 9). Unlike swash mark, rhomboid ripple mark appears on bedding surfaces of various orientation. Kindle[14] refers to the pattern as "imbricate wave sculpture"; Twenhofel[15] as "rhomboid ripple mark"; and D. W. Johnson[16] and W. O. Thompson[17] as "back wash mark."

[11] S. H. Knight, "The Fountain and the Casper Formations of the Laramie Basin," *Univ. Wyoming Pub. Sci. Geol.*, Vol. 1, No. 1 (1929), p. 58, Fig. 24.

[12] W. H. Twenhofel, *Principles of Sedimentation* (1939), p. 562.

[13] E. M. Kindle, "Recent and Fossil Ripple Mark," *Canada Dept. Mines Mus. Bull. 25*, Pl. XIX A, p. 93.

[14] E. M. Kindle, *op. cit.*, Pl. XIX B, p. 93.

[15] W. H. Twenhofel, *op. cit.*, p. 524.

[16] D. W. Johnson, *Shore Processes and Shoreline Development* (1919), p. 517.

[17] W. O. Thompson, "Original Structures of Beaches, Bars, and Dunes," *Bull. Geol. Soc. America*, Vol. 48 (1937), p. 737.

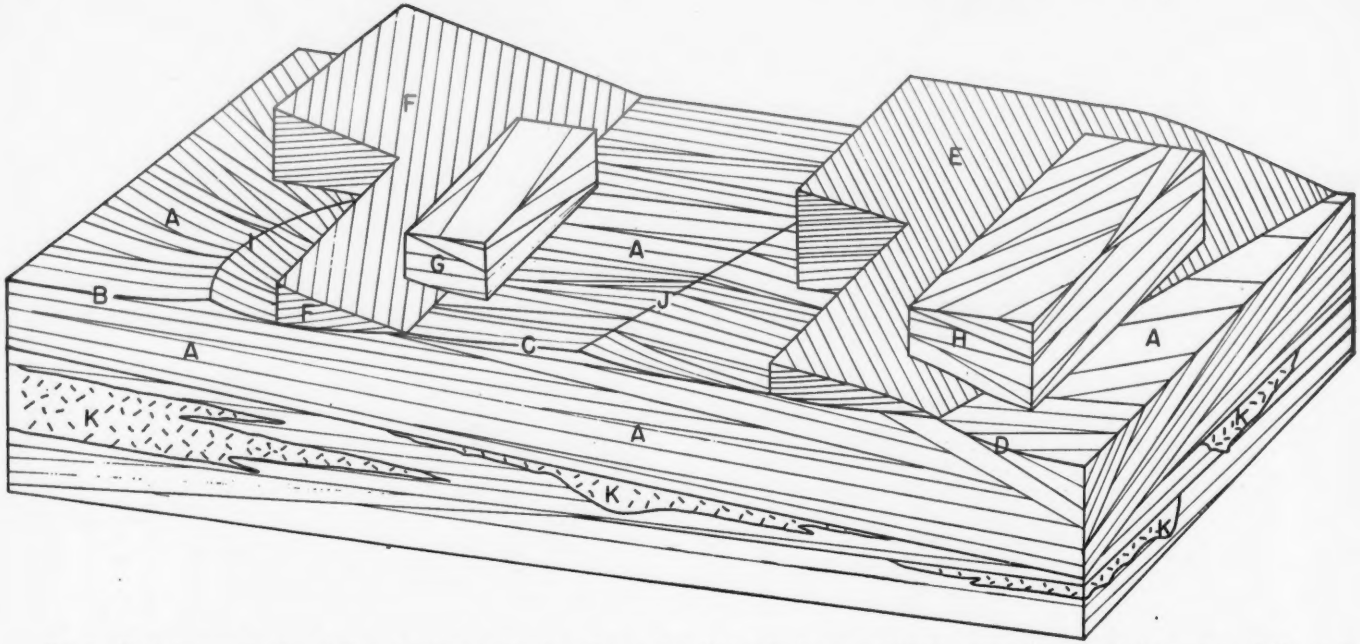


FIG. 6.—Block diagram showing relations of surfaces and laminae. Groups of southward-dipping cross-bedded laminae *A*, are truncated by surfaces *B*, *C*, and *D*. Surface *D* also transects surface *C* and westward-dipping laminae *E* for which surface *C* is floor of deposition. Similarly surface *C* transects surface *B* and westward-dipping laminae *F* for which surface *B* is floor of deposition. Surfaces *C* and *D* act as floor of deposition for eastward-dipping laminae *G* and *H*. Curved surface *I* is one of several scoop-like embayments. Low ridge *J* discloses typical intersection between two surfaces that are not quite parallel. Arkose lenses *K* disclose buried channel structures near base of formation.

Bubble impressions.—In many places the bedding surfaces of the Lyons are marked with circular impressions known as "bubble impressions" or "rain prints" (Fig. 10).

In typical form the impression is a crudely circular thread-like ridge of sand about $\frac{1}{32}$ inch high and $\frac{1}{2}$ inch in diameter. Its form is that of a very flat crater except that the part within the ring is not much depressed below the general level of the surface of the bed. Many are so closely spaced that the rim of one ring is in contact or even intersects that of an adjacent one.

This feature probably does not result from the washing of loose sand following the impact of rain drops. Just how the rim of the ring is preserved to become a part of geologic record is difficult to imagine, especially in view of the large number of such preservations. The required meticulous coordination between rainfall and suitable conditions of preservation is almost fantastic. An agency which is continually active seems more probable. The escape of bubbles of air trapped in dry sand by abrupt flooding of wave swash seems to be indicated. Alternate drying and flooding could then produce the numerous craters on bedding surfaces of the Lyons sandstone.

Dendritic figures and kelp marks.—The bedding surfaces of many slabs of Lyons sandstone are decorated with fern-like figures of manganese or iron oxide commonly confused with fossil ferns by the layman. Most of these figures extend, laterally for several square feet, but have only slight vertical dimension. These figures dominantly are black, a few are brown, all are confined to bedding surfaces.

A few larger figures of much coarser design penetrate the slab with nearly as much vertical as lateral dimension. In such places considerable increase in the porosity of the slab, where the figures penetrate, is noted. It is as if some substance long since decayed, held apart the grains of sand during the time of deposition. In form and size such plant-like figures resemble masses of kelp buried in modern beaches, hence are referred to as kelp marks.

ANIMAL TRACKS

At least two types of animal tracks are described from the Lyons sandstone. Because these tracks have a bearing on correlations, a short review of track description is included.

Henderson[18] describes, figures, and names one of these tracks which seem to be tracks of a Paleozoic amphibian, *Limnopus? coloradensis.* Gilmore, rendering an opinion in Lee's[19] paper, contends that Henderson's *Limnopus* is unquestionably *Laoporus* a genus founded by R. S. Lull on tracks, identical with those described by Henderson, from the Coconino sandstone of Arizona. Lull in-

[18] Junius Henderson, "Footprints in Pennsylvanian Sandstones of Colorado," *Jour. Geol.*, Vol. 32, No. 3 (April-May, 1924), pp. 226–29.

[19] Willis T. Lee, "Correlation of Geologic Formations between East Central Colorado, Central Wyoming and Southern Montana," *U. S. Geol. Survey, Prof. Paper 149* (1927), p. 12 and Pl. 33.

dicates that hereafter this track will be referred to as *Laoporus coloradoensis* (Henderson).

Toepelman and Rodeck[20] describe and figure another very different track as *Paleohelcura lyonsensis*. They do not assign it to a particular group of animals, but do suggest that it is probably of invertebrate origin. Confirmation of this idea comes from a recent paper by L. F. Brady,[21] who in working with Coconino tracks similar to those of Toepelman and Rodeck from the Lyons, concludes that *Paleohelcura* is almost certainly a scorpionid.

Sets of identical tracks of two different groups of animals in two widely separated sandstones, the Lyons and the Coconino, are significant in the light of additional information from other sources presented in following paragraphs.

RELATIONS WITH ADJACENT SEDIMENTS

From the foregoing description the Lyons sandstone is considered a lithologic unit with certain definite characteristics. Its texture, lamination, and cross-lamination are distinctive. Moreover, it is a ridge-making sediment which crops out regularly throughout most of the outcrop zone on the east side of the Front Range of Colorado.

The Lyons sandstone, however, is not everywhere the cohesive, easily delineated unit one might visualize from reading its description. Rather, the true Lyons seems to be the product of a recurrent type of sedimentation which dominates only parts of a much thicker deposit of sediment. It is interstratified above, below, and within with sediments whose characteristics group them naturally either with overlying or underlying formations. This is especially noticeable along the outcrop between Ralston Creek and Red Canyon, but is by no means limited to this area.

In general, the size of clastics with which the Lyons is interstratified, decreases south to north. At Red Canyon, south of Colorado Springs, coarse arkosic sandstone occupies the entire Lyons interval. At all places north of Red Canyon to Ralston Creek, this coarse arkosic sandstone is interstratified, not only with the base of the Lyons, but within and above it. An exception exists in the Colorado Springs embayment where interstratification with coarse arkose seems to be restricted to the lower part of the Lyons. In many places between Perry Park and Ralston Creek, coarse arkose actually overlies the uppermost layer of Lyons sandstone.

Between Ralston Creek and the type locality at Lyons, the coarse arkosic sandstone is interstratified only with the lowermost members of the Lyons. This zone is approximately 75 feet thick in most places. Layers of typical quartzose Lyons sandstone are overlain by lenticular arkose beds whose floors of de-

[20] W. C. Toepelman and H. G. Rodeck, "Footprints in Late Paleozoic Red Beds near Boulder, Colorado," *Jour. Paleon.*, Vol. 10, No. 7 (1936), p. 660.

[21] L. F. Brady, "Invertebrate Tracks from the Coconino Sandstone of Northern Arizona," *Jour. Paleon.*, Vol. 21, No. 5 (1947), pp. 466–72.

position cut into and even through earlier layers of Lyons sandstone. The arkosic layers in turn are overlain by other Lyons layers. Repetition of these relations continues throughout the 75-foot transition interval. A typical and very instructive exposure of this transition zone crops out in the north bank of South St. Vrain Creek about a mile southwest of the town of Lyons. Relations are portrayed in Figure 11. At the west end of the outcrop, above typical Fountain arkose, 35 feet of interstratified Lyons sandstone and Fountain arkose are subjacent to 20 feet of typical cross-bedded Lyons sandstone. A lenticular buried channel of Fountain arkose 20 feet wide and 10 feet deep rests on this 20-foot Lyons member. Traced eastward the lenticular channel of arkose lenses into pink cross-bedded slightly arkosic quartzose sandstone. The arkose lens and the pink sandstone underlie a lens of cross-bedded white eolian sandstone, in which the individual laminae dip westward against a regional east dip of approximately 15 degrees. Examination of the sand grains of this lowermost white lens discloses the fact that most of them are spherical, frosted, and uniformly grouped into two sizes, the larger of which is the smaller per cent. This white sandstone thins westward from about 30 feet to less than a foot at the westward end of the outcrop. A thin intraformational conglomerate overlies the white sandstone. In most places this conglomerate contains angular fragments of laminated red sandstone, some of them 6 inches in diameter. These sandstone fragments, which resemble typical Lyons sandstone seem to be derived from earlier deposits. The conglomerate, like the arkose and pink sandstone, is a channel deposit. The greatest thickness is 6 feet. Typical cross-bedded Lyons sandstone overlies this section.

Between the town of Lyons and the Colorado-Wyoming boundary, the Lyons sandstone gradually disappears. Thinning is very marked between Lyons and Stout. North of Stout, the thickness is fairly uniform but decreases gradually to ultimate disappearance of the recognizable sandstone unit near the north boundary of Colorado (Fig. 2).

The strata on which the Lyons rests also change northward. A short distance north of Lyons, the arkosic sandstones of the southern area gradually are dominated by red uniformly sorted, cross-bedded, quartz sandstone. This domination of quartz sand over arkose increases from south to north. Some red sandy shales appear in the section. These strata, herein designated the "lower Satanka tongue," separate the Lyons from the underlying "Ingleside tongue" of the Casper formation as restricted by Knight[22] (Fig. 2).

Between Dowe Pass and the Colorado-Wyoming boundary, bright red sandstones and shales interstratified with bedded gypsum and platy marine limestone overlie the Lyons sandstone. In some places tabular hexagonal crystals of dolomite, pseudomorphous after aragonite, crop out. Neither the gypsum nor the limestone is present in all sections and in some sections red sandy shale and red sandstone only, appear. East of Table Mountain in northern Colorado, one, and

[22] S. H. Knight, *op. cit.*, p. 49.

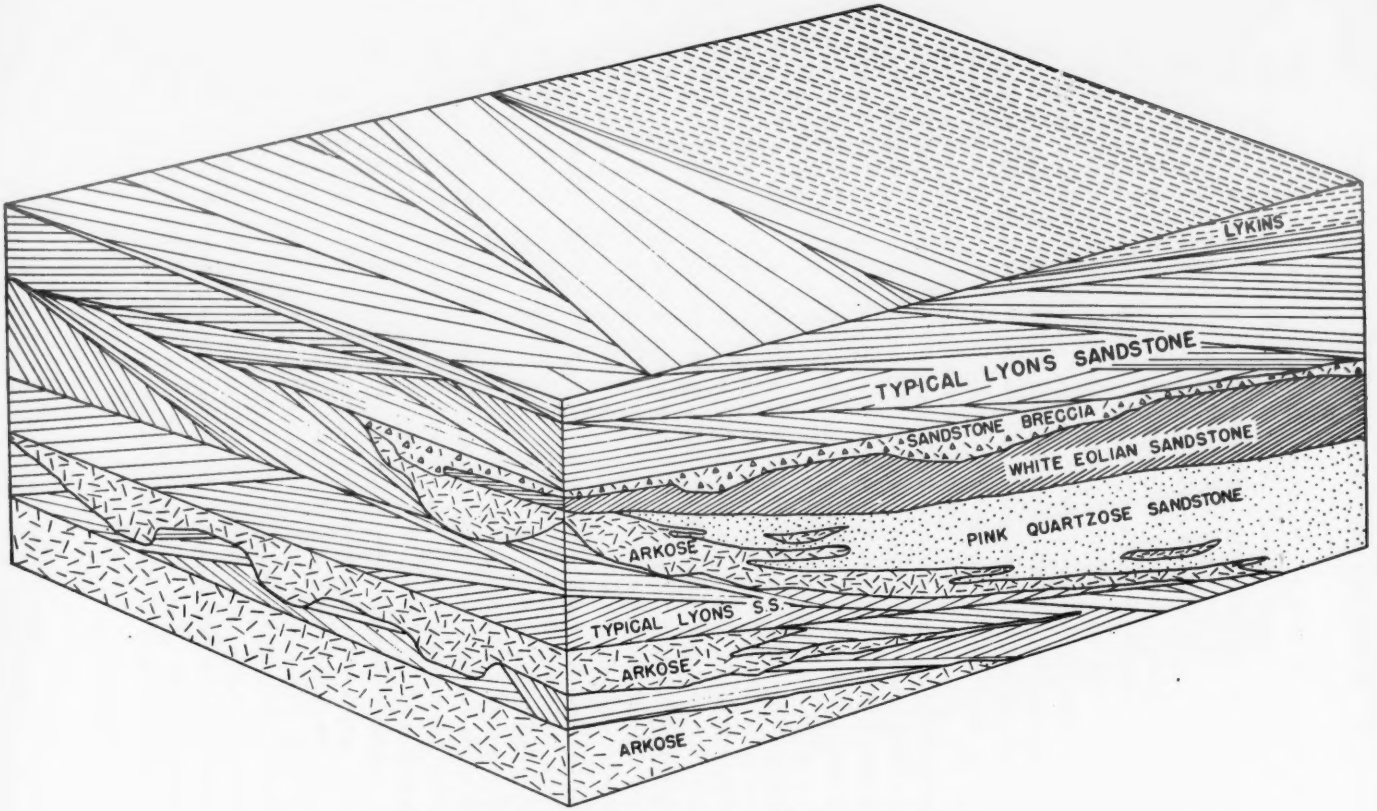


FIG. 11.—Relations of Arkose and Lyons sandstone in transition zone.

in some places, two thin sandstones which closely resemble the Lyons lithologically underlie the main outcrop and are separated from it by a few feet of red sandstone. Some fairly abrupt variations in thickness of the several described units is discerned in the vicinity of Table Mountain. In a few places, notably on Sand Creek and Box Elder Creek (T. 11 N., R. 70 W.), layers of marine gastropods and pelecypods appear in thin interstratified platy limestones. These fossils are described below. The thickness of sediment between the Lyons sandstone below and the Crinkled sandstone (Forelle) above is referred to as the upper Satanka tongue (Fig. 2). This unit includes strata designated Glendo, Minnekahta, and Opeche by Condra, Reed, and Scherer.[23]

ORIGIN

To explain the peculiarities of typical Lyons sandstone, N. M. Fenneman[24] invokes shore processes; A. J. Tieje,[25] wind; and C. E. Vail,[26] wind and stream processes. All are impressed by the remarkable lamination that characterizes the typical Lyons outcrop. Because of this lamination, the high quartz composition, and uniform sorting, it seems probable that no agents of sedimentation other than shore processes, streams, and wind were significantly involved in the deposition of the "Lyons facies."

It should be re-emphasized that the Lyons is not everywhere a cohesive, easily delineated stratigraphic unit; but rather the product of a recurrent, distinctive type of sedimentation which dominates some parts of a thicker stratigraphic unit. This "Lyons facies " is interstratified, above, below, and even within, with sediments whose characteristics group them naturally either with underlying or overlying formations; that is the Fountain formation; the lower Lykins formation; or the upper and lower Satanka tongues.

Fountain sedimentation is almost certainly the result of fluvial activity as is adequately demonstrated by Knight.[27]

Tieje's[28] treatment of the lower Lykins as an upper delta is a reasonable explanation.

If stream hypotheses of deposition are accepted for Fountain and Lykins sediments, the adoption of a different agent or agents for deposition of the Lyons seems mandatory because of the sharp contrast in composition, textural attributes, and original structures between the Lyons and the Fountain and Lykins stream-laid sediments. That a stream depositing the crudely sorted arkosic sand of the Fountain should change abruptly to the deposition of uniformly sorted and

[23] G. E. Condra, E. C. Reed, O. J. Scherer, *Nebraska Geol. Survey Bull. 13*, p. 10.

[24] N. M. Fenneman, *op. cit.*, p. 60.

[25] A. J. Tieje, *op. cit.*, p. 201.

[26] C. E. Vail, *op. cit.*, p. 2.

[27] S. H. Knight, *op. cit.*, p. 29.

[28] A. J. Tieje, *op. cit.*, p. 205.

laminated quartz sand and then change back to arkosic sand, is improbable. This abrupt change alone makes it seem improbable that stream activity is an important agent in the deposition of typical Lyons sandstone. In addition, the excellent sorting, high degree of lamination, opposition of dip but parallelism of strike of laminae, and the extensive truncating surfaces of the Lyons are features which are not characteristic of sediments of fluvial origin.

With fluvial deposition eliminated, wind and shore processes are left as probable agents of deposition. Both agents bring about the high degree of concentration of quartz sand which characterizes all typical Lyons outcrops. Both can produce the textural attributes of the Lyons, even to the surface texture of the grains, which Maxwell[29] finds is almost equally distributed between frosted or "matte" surfaces produced by the wind and clear glassy surfaces attributed to handling by water.

That shore processes did operate in the formation of the Lyons, is manifest, particularly, in the arrangement of the extensive truncating surfaces, in the laminae of variant dip but approximate parallelism of strike, and in the uniform sorting as to size within individual laminae.

The complex relation of truncating surfaces and truncated laminae portrayed in Figure 6 is most readily explained by a shore hypothesis. The sequence of events recorded by these complex relations in the Lyons quarries is interpreted in the light of direct observation of beach erosion and deposition by the writer[30] before, during, and following a heavy storm which modified beaches at Balboa, California. A parallelism is drawn between the results of deposition of the storm sequence at Balboa and the features found in the Lyons quarries.

The Balboa storm sequence begins activity on a relatively thick cusped beach which had developed during an extended period of calm. Normal tides immediately preceding spring tides had prevailed. A high tide raised the level of the water so that lashing storm waves carried back to deep water much of the material previously deposited on the beach. Strong littoral currents accompanying the storm carried the material offshore. The sea offshore for a mile was badly discolored from suspended sediment. A wedge shaped segment of beach 10–15 feet thick at the land side, 60 or more feet wide and many miles long was removed from the original pre-storm beach surface. The post-storm surface was correspondingly lower and was flanked on the landward side by a vertical seaward facing scarp 10–15 feet high. Gradual return of the material carried offshore by the storm began as soon as the weather calmed. The return of this material was concurrent with the gradual development of spring tide, hence material was carried progressively higher and farther inland with each succeeding high tide. The first deposit following the storm was a low beach ridge formed at the landward reach of the waves at high tide, but 50 or more feet from the storm scarp.

[29] J. M. Maxwell, *op. cit.*, p. 34.

[30] W. O. Thompson, *op. cit.*, p. 734.

Some sediment of this ridge dipped landward, some seaward. With each succeeding higher tide, waves carried sand from the seaward to the landward side of the beach ridge and thus gradually worked the crest farther and farther landward as well as progressively higher. This process continued for several weeks until the maximum high high spring tide was reached. At this time landward-dipping sediments carried over the crest of the beach ridge reached the base of the original seaward facing scarp left by the storm. Thereafter during the gradual retreat of the spring tide, laminated sediments were deposited only on the seaward side of the beach ridge. In many places, depending on the depth of wave scour, this was upon the truncated edges of the landward-dipping sediment formed during the landward advance of the beach ridge. Beach cusps redeveloped on the seaward side of the beach surface during the regression of the sea following the maximum high high tide.

In the Lyons quarries (Fig. 6) southward-dipping cross-bedded laminae *A*, though they were probably deposited on the shoreward side of ancient barrier bar of which the general trend was eastward, correspond with the uneroded sediment left on the beach after the storm at Balboa. The course of the ancient bar at Lyons seems to have been modified by the storm waves and currents that destroyed the upper part of the bar and formed the surface *B* which corresponds with the post-storm surface of the beach at Balboa. Surface *B* at Lyons seems not to have been buried immediately as was the post-storm surface at Balboa; or if surface *B* was buried, subsequent storms cut deep enough into the overlying materials to transect surface *B* in places. Surface *B* then becomes a composite of surfaces each with a slightly different attitude (Fig. 5), thus developing structures like ridge *J* and scoop-like embayment *I* (Fig. 6). Surface *B*, following its ultimate completion, is then buried by cross-laminated westward-dipping sediment *F* in Figure 6. These sediments are comparable with those deposited on the landward side of the beach crest at Balboa.

Surface *C* in Figure 6 and westward-dipping laminated sediment *E* result from a later similar sequence inasmuch as they resemble surface *B* and laminae *F* but overlie them.

Cross-laminated sediments *G* and *H* (Fig. 6) are deposited on eastward-sloping surfaces transecting westward-dipping laminae, thus corresponding with sediment left on the seaward-sloping surfaces that cut the landward-dipping laminae at Balboa following the high high spring tide. Sequence *B*, *F*, *G* is followed by sequence *C*, *E*, *D*, *H*, and it should be understood that probably many similar but unrecorded sequences took place before these two recorded sequences managed to become a part of the permanent geologic record.

The crude parallelism of strikes of laminae, except across major breaks like surface *B* cut into laminae *A*; and the opposition of dips in sheaves of laminae, as *G* against *F* or *H* against *E*, are not readily explained except by a shore-process hypothesis.

Uniform sorting as to size within individual laminae and abrupt contrast in

size from lamina to lamina are distinctly characteristic of recent beaches[31] and are present in the Lyons sandstone.

Minor original structures like swash mark and backwash mark are not easily misinterpreted. Their presence in the Lyons sandstone is a strong argument in favor of a shore-process hypothesis of origin.

From these several physical features of the Lyons sandstone comes the conviction that shore processes have played a very important part in deposition; not, however, to the exclusion of the wind as an important secondary agent. This is natural, as can be verified by the examination of any recent shore. Almost invariably, present-day beaches are involved with dunes; hence, there is no reason to suppose that Permian beaches were not similarly involved.

Dune sands contain extensive, though undulating truncating surfaces; but these surfaces are not like the plane surfaces which characterize the Lyons sandstone. The attitude of laminae of dune sands, moreover, is extremely variable both as to direction and angle of dip. Dune sands do not display the approximate parallelism of strike which characterizes laminae of both the Lyons and modern beaches. Hence, deposition of the Lyons does not seem to result primarily from eolian activity. That dunes did prevail at times is adequately recorded southwest of Lyons on South St. Vrain Creek by the lense of sandstone containing typical eolian frosted grains of two sizes, the larger of which composes the smaller percentage (Fig. 11).

Once the general concept of beach origin is accepted, numerous otherwise seemingly passive considerations fall into place in the general scheme. Their collective weight presents compelling argument in favor of the involvement of shore processes.

Thus, the widespread distribution and the uniform thickness of the Lyons are adequately accounted for; the questionable bubble impressions and kelp imprints become probabilities; and the interstratified relations of Lyons with arkosic Fountain sediments denotes contest between the activity of streams pushing the shoreline seaward by the deposition of fluvial sediment and the activity of waves and littoral currents transgressing landward by reworking these stream sediments. That both processes alternately succeed temporarily is recorded in the successive alternation of fluvial arkose and beach sand. That this alternation should result in the formation of local lagoons or basins in which the gypseous and calcareous sediments of the northern part of the area could be deposited, seems probable. That places appear where either or both of these gypseous or calcareous sediments is absent and is apparently substituted by red sandstone, seems fitting. That occasionally a few brackish-water forms of invertebrates appear, is to be anticipated in the inferred environment.

To the foregoing implications should be added the fact that both below and above the Lyons, in the adjacent stratigraphic column, thin layers of fossiliferous

[31] W. O. Thompson, *op. cit.*, p. 726.

limestone of undoubted marine origin are interstratified with continental sediments. This indicates the alternate presence in the same area of agents which deposit both marine and continental sediments. Hence, there must have been alternate transgression and regression of the sea across such places as contain, interstratified, both continental and marine sediments. Since this is precisely the condition in nature under which beaches develop, the presence of an ancient beach with this part of the late Paleozoic section is to be anticipated. Barrell[32] points out that beaches, if they are to become a permanent part of the geologic record, require for preservation very special geological conditions. The preservation of a Lyons beach seems to be readily explained by abrupt burial of the Lyons sediment by rapidly deposited overlying Permian-Triassic redbeds of the Lykins formation.

The foregoing accumulation of characteristics point to the conclusion that the dominant agent of deposition of the Lyons sandstone is a shore process involving waves and littoral currents.

AGE AND CORRELATION

The Lyons sandstone contains no fossils from which its age might be established. Three sets of facts when combined, however, seem to link the formation with Middle Permian strata of West Texas. Not improbably the Lyons is no older than Leonard and no younger than Guadalupian (Word).

1. Fossils are found in two localities where the Lyons is interstratified with beds which are probably of Leonard in age. Near Table Mountain in northern Colorado (Livermore Quadrangle), typical Lyons sandstone underlies the upper Satanka tongue (Fig. 2). Within this tongue stratified gypsum, red sandstone and shale, and thin limestone strata are closely interbedded. At least three of the limestones contain invertebrate fossils. Renfro[33] collected and described the following:

Allula squamulifera Girty; *Bellerophon* sp.; and *Aviculopecten jodiae* Renfro n. sp. Renfro finds both *Allula* and *Aviculopecten* in the Satanka shale of southeast Wyoming and in the Kaibab limestone of southern Utah. On the basis of these and other invertebrates in the Satanka of southeast Wyoming, he thinks that the Satanka, the Lyons, and that part of the Kaibab limestone which contains "*Bellerophon* beds" are of the same age. Inasmuch as Baker and Williams[34] state that the Kaibab contains a marine fauna which generally is considered to be of approximately the same age as the fauna of the Leonard formation of West Texas, Renfro's age correlation seems probable.

In Perry Park north of Colorado Springs, a thin limestone bed above the

[32] Joseph Barrell, "Relative Importance of Continental, Littoral and Marine Sedimentation," *Jour. Geol.*, Vol. 14 (1906), p. 444.

[33] H. B. Renfro, personal communication (1941).

[34] A. A. Baker and James Steele Williams, "Permian in Parts of the Rocky Mountain and Colorado Plateau Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 4 (1940), p. 621.

Creamy sandstone also contains invertebrate remains. Newell[35] says of these fossils

> . . . contains species which clearly belong to the so-called Lykins fauna of George Girty. . . . A *Myalina* . . . similar to a species from the White Horse formation. . . appears certainly of Permian age . . . probably equivalent to the Guadalupian or Ochoa.

The Lyons sandstone and its equivalent, the Creamy, underly these thin, fossil-bearing limestone beds. At the Table Mountain locality, the Lyons is 175 feet above the top of the Ingleside formation which Miller and Thomas[36] consider equivalent to the upper part of the Casper formation. They believe that the Casper is probably Upper Pennsylvanian rather than Lower Permian; hence the Lyons sandstone is younger than Upper Pennsylvanian, but older than the thin limestones which are correlative with either the Kaibab or the White Horse. This suggests that the Lyons is either Leonard or Guadalupian (Word).

2. Baker and Williams[37] indicate that the Kaibab is interstratified with the Coconino in southern Utah. The occurrence of animal tracks, *Laoporus coloradoensis* (Henderson) and *Paleohelcura*, in both Lyons and Coconino sandstones suggests the correlation of the Lyons with the Coconino, hence Kaibab, and supports the evidence from invertebrate remains.

3. In western Colorado recent studies of well cuttings and surface sections by the writer disclose the fact that the so-called Weber sand of the Rangely oil field thins eastward gradually, eventually to disappear among the red sediments on the west slope of the Gore Range about 10 miles east of Eagle, Colorado. For convenience, this sandstone is referred to as the "Schoolhouse sand" because of an excellent typical outcrop near a schoolhouse east of Meeker, Colorado. In certain sections the lithologic character of the "Schoolhouse sand" is remarkably similar to that of the Lyons on the east side of the Front Range. Moreover, the position of the "Schoolhouse" below thin platy limestones almost identical with those of the "Crinkled limestone" (Forelle) of the Front Range strongly suggests that the "Schoolhouse sand" is the approximate equivalent of the Lyons sandstone. If this correlation is accepted, the "Schoolhouse" becomes upper Weber (probably Coconino) and again the indirect linking of the Lyons with the Kaibab through Coconino is suggested.

Inasmuch as all three inferences, even though sketchy in places, lead to similar conclusions regarding age, the Lyons is probably Middle Permian, approximately equivalent to the Leonard formation of West Texas.

[35] Norman D. Newell, personal communication (1940).

[36] A. K. Miller and H. D. Thomas, "The Casper Formation of Wyoming and Its Cephalopod Fauna," *Jour. Paleon.*, Vol. 10, No. 8 (December, 1936), pp. 723–24.

[37] A. A. Baker and J. S. Williams, *op. cit.*, p. 622.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 1 (JANUARY, 1949), PP. 73-91, 7 FIGS.

SAMPLING AND EXAMINATION OF WELL CUTTINGS[1]

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ABSTRACT

Samples of well cuttings are one of the chief sources of information concerning the formations of the subsurface in the Mid-Continent and Permian basin areas of the United States. By careful use in applying the methods of collecting and preparing these samples as described in this paper, it is possible to obtain cuttings samples which are truly representative of the formations penetrated. By microscopic examination of these samples, it is possible to prepare descriptions and plotted logs which give an accurate picture of the rocks penetrated. These logs can be correlated so as to reveal the stratigraphic conditions in the subsurface and trace time horizons through various facies variations of the subsurface formations. These time horizons can be used in the structural interpretation of the region.

Detailed descriptions of cuttings samples from pay sections can be used, by methods outlined in this paper, in making estimates of oil and gas recovery from a field, in reservoir studies, and in guiding well remedial work.

INTRODUCTION

While the techniques described in this paper have been learned during 14 years of subsurface work, the writer does not wish to give the impression that they are original with him. They are rather the results of many years experience of hundreds of geologists engaged in cuttings sample work, which are summarized especially for the benefit of those entering the profession or setting up subsurface departments in other regions.

Well cuttings are the source of most subsurface data obtained in the Mid-Continent and Permian basin areas of the United States. The collection and examination of samples of these well cuttings are highly organized and important techniques. In fact, in most holes in this province, well cuttings are the only reliable source of data concerning the formations penetrated. Logs made by experienced cable-tool drillers are very useful, but under present conditions these are rare. It is usual to find the drillers' log made by an inexperienced or uninterested rotary driller. Such a log gives only a general idea of the formations drilled, especially in areas where there is a distinct formation change between wells.

Of all the methods of obtaining information concerning rocks cut by the drill, cores are probably the most reliable. In soft unconsolidated formations these cores can be taken rapidly and with comparatively little expense, by means of a wire-line core barrel. However, in the Mid-Continent and Permian basin areas most of the rocks are well lithified and many are extremely hard. For this reason wire-line core bits wear out rapidly and cores are usually obtained by use of conventional core barrels which are capable of cutting a maximum of 20 feet at one time. Naturally this makes complete coring extremely expensive especially

[1] Manuscript received, August 4, 1948.

[2] Consulting geologist. The writer is especially indebted to W. D. Anderson, who taught him the fundamentals of sample examination; to William Y. Penn for the pictures of porosity; to E. Russell Lloyd who suggested the writing of this paper and has been generous with help and suggestions; and to John Emery Adams and W. W. West who kindly read and criticized the manuscript.

in deep holes. Recently a new technique of coring with diamond-studded core heads has been developed which may lead to much more extensive coring. It is possible that in the future as much as 100 feet of core may be taken at one time by means of a diamond bit without coming out of the hole. This may render practicable coring of complete sections of deep holes.

ELECTRICAL LOGS AND RADIOACTIVITY LOGS

Electrical-resistivity and self-potential logs have almost supplanted cutting samples and cores in areas where the stratigraphic section is shale and sand and where salt beds do not contaminate the drilling mud. However, in areas where the section is composed of several kinds of rock, especially where limestone and anhydrite are abundant, electrical logs must be used with sample logs since the lithologic variety and high resistance of the rocks introduce many unknowns into the interpretation of the log. Thus, it is impossible to solve the problem without a sample log which will enable one to eliminate many of the possible solutions.

In limestone reservoirs it is very difficult to recognize the fluid content of the reservoir rock by use of electrical logs without additional information from testing the well, because the high resistivity of the limestone and the sulphur water commonly present mask the resistivity effects of the other fluids in the formation. However, electrical logs are useful for correlation in local limestone reservoirs where the section is well controlled by logs from sample cuttings. One fact that should be remembered in using electrical logs is that rock-salt beds cut by the bit cause a salty mud with a very low electrical resistance, that results in a featureless self-potential curve which is useless in making correlations.

Radioactivity logs are also useful as an auxiliary to sample logs. Here, also, a wide variety of rock and fluids in the stratigraphic column results in several possible interpretations for the curve, and a sample log is necessary for the correct solution. Radioactivity logs are sometimes very useful in logging old wells that have already been cased off or wells where mechanical difficulties have prevented taking a representative set of cuttings. Radioactivity neutron logs are probably more useful than resistivity logs in indicating a fluid zone, but it is not possible from the neutron log alone to determine whether the fluid content of the formation is oil or water.

Thus, in areas where consolidated formations are encountered, examination of well cutting samples is generally the easiest and least expensive method of detecting changes in the formation and determining the stratigraphic section penetrated by any well. Much subsurface geologic work depends on the collection of representative samples of the formation penetrated, describing these samples accurately, and plotting the description so that the sections in different wells may be correlated.

CABLE-TOOL SAMPLES

The collection of cuttings samples from cable-tool wells presents comparatively few difficulties. The samples should be collected from the first bailer after

each run of the bit, in a bucket hung at the end of the dump box. These samples should be washed enough to carry off all mud. They should be put in cloth sacks, then labeled with the name of the company, name of the farm, number of the well location, and depth of sample. The hole is, of course, bailed clean each run of the bit and only occasionally are cavings a problem in consolidated formations.

In drilling bentonitic shales, quicksands, or conglomerate, the hole ordinarily caves readily so that the samples are not entirely reliable. When high pressure gas is encountered, the hole is commonly filled with water or light mud to control the gas. This ordinarily results in samples being finely ground and much material is washed off the upper parts of the hole, which contaminates the samples. The same condition results from drilling ahead in a hole full of water coming from the formation. Generally, under these conditions, pipe is run before much hole is made so that the number of poor samples is comparatively small. Where wire line or tools have been lost in the hole and must be drilled up, some samples contain large amounts of iron. This can be removed by means of a magnet and the residue of the sample examined. Surface rock and other materials sometimes are thrown into the hole in attempting to straighten it.

The problem of checking the depth at which samples are taken is not critical with cable tools, since the depth is checked by sand line on the bailer after each run. However, important datum beds in the section should be checked for depth by stringing in the sand line or by running a steel measuring line. Cable-tool samples differ from rotary samples by the general flaky character of the harder formations and by the polishing and rounding of many cuttings from attrition due to turbulence set up by the bit, and the irregular intervals at which they are taken, since the length of bit runs are determined by the character of the formation and mechanical factors.

ROTARY SAMPLES

The collection of rotary samples presents many more difficulties than the collection of cable-tool samples and for many years it was considered impossible to obtain reliable samples by this method of drilling. It is still difficult to obtain representative samples from rotary holes in unconsolidated formations, but a technique has been worked out whereby representative samples can be obtained in consolidated formations. These samples are taken from the returning fluid stream at regular intervals. The sample interval is usually 5 or 10 feet, but may be as small as 1 foot or as large as 30 feet. The chief problems in collecting samples of rotary cuttings are to prevent contamination with upper beds, prevent powdering of the sample, prevent loss of the sample, prevent elutriation, to obtain correct depth measurement, and to wash and properly dry the samples.

CONTAMINATION FROM UPPER BEDS

Contamination from upper beds is the chief problem of collecting rotary samples. In the early days of rotary drilling before mud building was fully under-

stood, the walls of the hole were poorly plastered and unstable. Thus, the samples contained large amounts of extraneous material. The practice of considering any new material appearing in the samples as composing the entire content of the formation drilled then became general and any other material was believed to be cavings. At present, however, the treatment of rotary muds has advanced so that usually a properly mudded rotary hole caves very little and the percentage content of the sample may be taken as representative of the types of rock in the interval covered. This enables the geologist to follow very closely the lateral gradations in the section.

It should be emphasized that the geologist must work with the drilling superintendent to insure the maintenance of proper mud in the hole not only for the sake of drilling progress but also for the securing of representative cuttings samples. The mud must have a gel strength and viscosity sufficient to bring the cuttings to the surface without recirculation and regrinding. It must be also capable of cushioning the impact of the drill pipe against the walls so as to prevent powdering of the samples. Once on the surface, the mud should be run through pits sufficiently large to insure settling of all the cuttings so that they will not recirculate. A shale shaker will insure complete separation of the larger cuttings and the mud.

POWDERING OF CUTTINGS

The powdering of the sample to a size too small to be examined effectively under the binocular microscope is largely due to poor mud which allows regrinding of the sample by the bit and powdering by whipping of the drill pipe against the walls of the hole. When extraordinarily large cuttings are needed for analysis of porosity and permeability or for other purposes, it is helpful to circulate in reverse of the usual manner, that is, to pump the mud down between the casing and drill pipe and up through the drill pipe. This results in higher mud velocities returning through the drill pipe which brings larger cuttings from the bottom as soon as they are chipped off by the teeth of the rock bit. Some of these cuttings are $\frac{1}{2}$–$\frac{3}{4}$ inch across.

Reverse circulation is especially useful when drilling into low-pressure formations, by using oil as drilling fluid as it prevents any of the fine oil-borne cuttings from plugging the pores of the formation. In regular circulation with oil, the low viscosity of the oil will not carry out the cuttings and they are commonly reground to a fine putty-like mass which is useless for examination and has a plugging effect on low-pressure pays. Of course, reverse circulation is not necessary in high-pressure gas or oil pays since the high pressures tend to increase the velocity of the circulating fluids and carry the cuttings out of the hole. The advantages of using a water-free drilling fluid in low-pressure oil pays are combined with the advantages of a high-viscosity mud in carrying out the cuttings and cleaning the formation in oil-base muds recently developed. With these muds it is not necessary to use reverse circulation to obtain cuttings large enough for

visual examination. However, since methods have been recently developed for determining porosity and permeability from extra large cuttings obtained by reverse circulation, this method undoubtedly still will be used to some extent in pay sections.

LOSS OF CUTTINGS

Loss of cuttings samples is due to two chief causes: lost circulation, and blow-outs. Both of these are primarily mud problems. Lost circulation is caused by either too high water loss in the mud or by excessively heavy mud which overcomes the formation pressure of a porous or fractured bed so that the mud enters the pores or fractures. The cuttings are then carried into the porous beds and may not ever be recovered unless the well is completed in this zone and the cuttings come out later with the oil. Blow-outs are caused by unexpectedly high formation pressures or by carelessness in handling the mud. The cuttings are blown out of the hole and not recovered.

ELUTRIATION

Elutriation or separation of the coarse from the finer part of the sample by the upward movement of the circulating fluid is due to the use of mud with low viscosity and gel strength. In a good mud the cuttings are held in suspension and there is little change in the relative position.

METHODS OF OBTAINING CORRECT DEPTHS

Obtaining proper depth measurement for rotary cuttings is another major problem. The depth of the well must be checked often either by steel measuring line or by measuring the drill pipe under tension. Attention must be given constantly to see that the crew catches the samples at the proper intervals and that they do not anticipate the sample by filling several sacks at one time.

A great help in assuring correct sample depth is to have the driller keep a record of the drilling time on a form, such as Table I. Each interval, 1, 5, or 10 feet, depending on the importance of the section, is shown on this sheet with the time drilling began, the time it ended, the time taken out for mechanical work, and the net time drilling. These intervals are usually marked on the kelly with grease or chalk and checked by the pipe measurement each time the kelly is drilled down to the derrick floor. In addition to assuring the correct depth of the samples, the drilling time gives a very valuable clue to the nature of formations penetrated as the time of drilling has a very close correlation with the lithologic character of the formation. This drilling time also may be taken with a mechanical device.

In pay sections where the exact measurements are very important or in deep holes where the cuttings take a long time to come to the surface, samples should be labelled with the depth at which they are actually cut rather than the depth of the well at the time they come to surface. This is accomplished by placing some

easily identifiable substance, such as rice or corn in the drill pipe at the derrick floor when making a connection, and measuring the time required to bring the substance around to the shale shaker or return pipe. If regular circulation is being used, it can then be calculated from the pump pressure and volume handled how long the mud requires to go from the derrick floor through the drill pipe to the bit, and this subtracted from the total return time gives the time necessary for

TABLE I

EXAMPLE OF DRILLING-TIME FORM

COMPANY_____ NO._____ FARM_____
LOCATION_____ COUNTY_____ STATE_____
WEIGHT ON DRILL PIPE_____ MUD WEIGHT_____ R.P.M._____ MUD VISCOSITY_____

DEPTH		DRILLING TIME		ACTUAL TIME	TIME OUT—REMARKS
FROM	TO	BEGAN	ENDED		

ACTUAL TIME IS TIME SPENT IN DRILLING. SHUT-DOWN TIME, ROUND TRIPS, CHANGING BIT, REPAIRS, ETC., ALSO CONDITION AND TYPE OF BIT SHOULD BE NOTED UNDER "REMARKS."

the samples to come from the bit to the surface. Unless it is known that the hole is in extraordinarily good shape with no washed-out places, it is not satisfactory to calculate the return time from the bit by mud volume and velocity, because some eddying and consequent lowering of the mud velocity takes place in all washed-out places. If it is not possible to determine the sample return time from experimental methods of calculation, a rule of thumb is that under ordinary mud pressure with 7- or 8-inch hole, it will take cuttings about 10 minutes per 1,000 feet to return from bottom.

After the return time of the sample is determined or estimated, each sample should be caught that length of time after the appropriate depth mark on the kelly reaches the rotary table. An easy way to do this is to place on the drilling-time sheet the time each sample should be caught. This is done by adding the return time in minutes to the time at which the given mark is down to the rotary table. This method will eliminate lag in the samples and should make the sample log correlate very closely with the drilling time and with the electrical log.

CATCHING SAMPLES

There are many ways to catch representative samples from the returning mud stream. The rotary shale shaker of the Thompson type has become very common in recent years. This is a large cylindrical screen through which the returning mud stream passes. The screen is turned by a water wheel moved by the mud stream. Attached to the large screen is a much smaller screen with fine mesh through which a portion of the main mud stream is diverted, off which comes a small portion of the cuttings which is collected in a box at the end of the screen for visual examination. This type of screen has the advantage that it requires no outside power to operate it, and it catches a representative sample of the cuttings without any further attention from the operator or crew. However, unless a very fine screen is used on the sample catcher, it will not catch all the fine sands. In some formations the mud will not wash out of the cuttings without use of an excessive amount of water which renders it unsuitable for use with low-water loss muds.

Another important type of screen commonly used is the vibratory shaker. In this device the mud stream passes across a vibrating screen. The mud passes through the screen into the pits while the cuttings are vibrating off into another receptacle. In consolidated formations good samples can be taken by placing a narrow box under a part of the end of the vibrating screen so that a representative portion will fall into this box. However, this screen is open to the same objection as the Thompson machine in formations consisting of fine sands, since the fine sand tends to pass through the screen and not be caught in the sample.

The simplest and possibly most reliable sample-catching device (Fig. 1) consists of a small-diameter nipple welded to the bottom of the mud return line with a $1\frac{1}{2}$-inch or 2-inch line running to a box about 1 foot by 1 foot by 3 feet with a removable gate about 6 inches high in the end. In this box a representative portion of the cuttings is collected and may be shoveled out at the appropriate time into a bucket and the box cleaned by removing the end gate and letting the mud stream carry out the remaining cuttings. When these are washed away, the gate is replaced and the collection of the next sample is begun. By this means a representative portion of both the fine and coarse parts of the cuttings is obtained. Sometimes such a box is set in the course of the main mud stream, but so many cuttings accumulate that the space behind the gate is filled with cuttings before drilling of the sample interval is completed so that the last part of the interval is not represented by the cuttings in the box.

After the samples are caught they must be washed properly. This can be done in a bucket by filling it partly full of water and stirring the samples vigorously, letting the clean part settle, decanting the fluid several times until the water is clear and sample is ready for sacking and labeling. Sometimes the sample is washed in a box with a fine-screen bottom. This hastens the washing process, but there is some danger of losing the fine sand from the sample. When drilling with

oil or oil-base mud, the sample must be washed entirely free of drilling fluid before it is dried. This can be accomplished by using hot water, although some prefer to wash with kerosene or gasoline before washing with water. One need have no fear of washing the indigenous oil stain and saturation from the sample as any ordinary washing will only remove the drilling oil and will not remove the natural oil from the formation.

After washing, samples are commonly dried artificially. However, in samples showing stain and saturation this must be done with extreme caution as over-

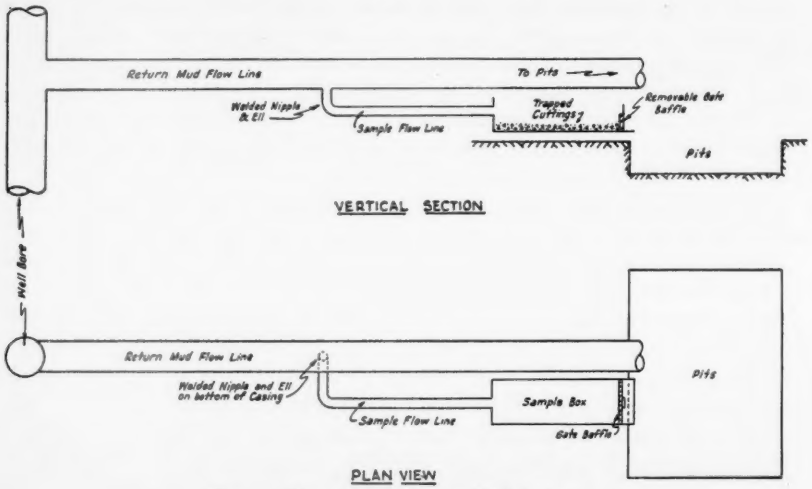


FIG. 1.—Diagram of sample-catching device.

heating will blacken the natural oil stain and mask the porosity as well as render it difficult to tell whether the formation fluid is oil, gas, or water. In extreme cases of overheating, red shales may be oxidized to a black color. If samples from wells drilled with oil-base drilling fluid are not washed clean before drying, it is impossible afterward to remove the drilling oil even by boiling the sample. In some cases where samples are to be used for paleontologic examination, any shale in the samples is digested with boiling water and soda to leave the fossils free. It is probably better when there is no necessity for haste in examination of the samples to let them dry naturally in the air rather than to dry them artificially.

After the samples are sacked and transported to the laboratory, it is commonly necessary to divide them into smaller portions for different types of examination or for examination by different individuals. This should not be done by merely pouring a little off the top of the sack as ordinarily there will be a few large cavings on the top of the sack. These should be raked off and discarded and the remainder of the sack mixed so every portion will be representative. All por-

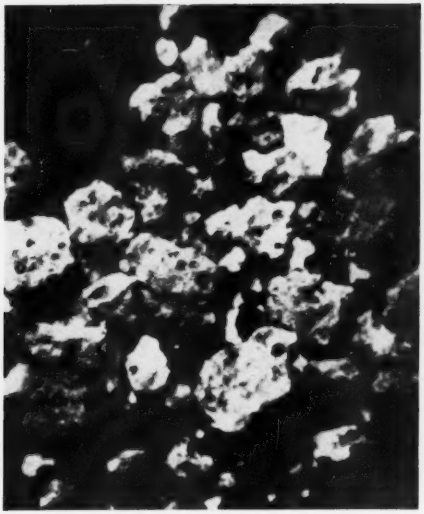


FIG. 2.—Very good leached oölitic porosity in dolomite. 5×. Champlin's University 1-D. 8,030–8,060 feet. Sec. 26, Blk. 13, Univ. Lands, Andrews Co., Tex.

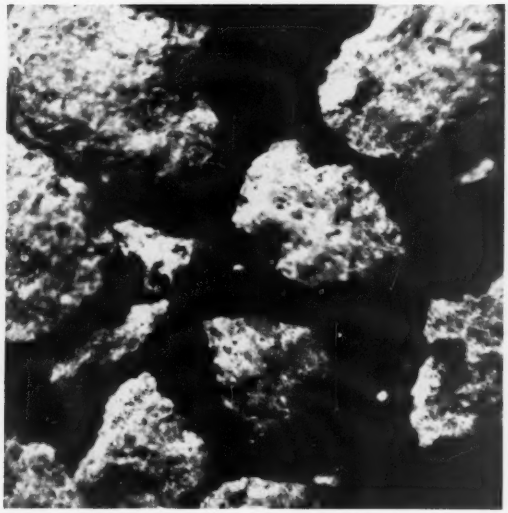
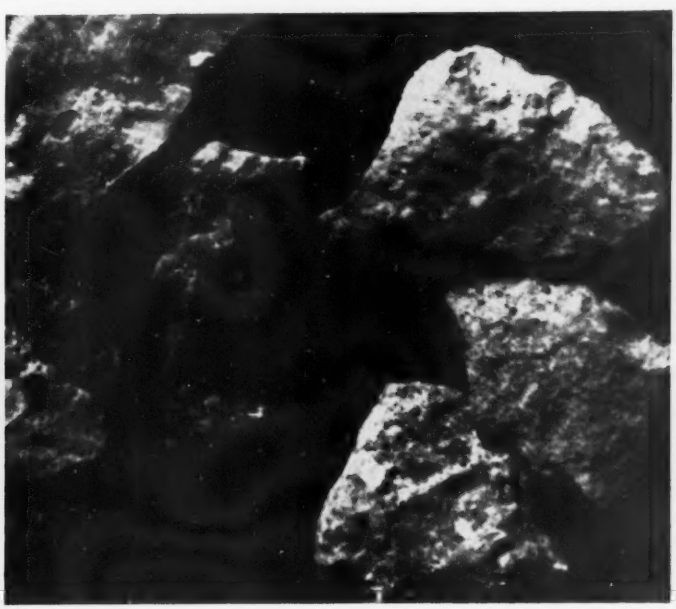


FIG. 3.—Granular dolomite with good intermediate type porosity. Reverse circulated cuttings. 10×. Penrose's University 2. 4,465–4,470 feet. Sec. 3, Blk. 10, Univ. Lands, Andrews Co., Tex.

FIG. 4.—Porous dolomite, apparently part of lining of fissure or vug. Note covering of free dolomite crystals. 5×. Penrose's University 2. 4,460–4,465 feet. Sec. 3, Blk. 10, Univ. Lands, Andrews Co., Tex.



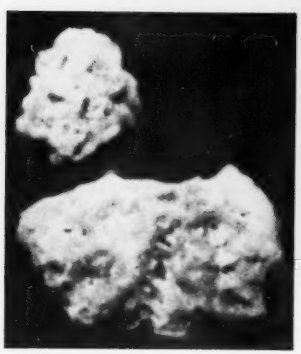


FIG. 5.—Isolated pin-point porosity in dolomite. Reverse circulated cuttings. 5×. Penrose's University 2. 4,410–4,415 feet. Sec. 3, Blk. 10, Univ. Lands, Andrews Co., Tex.

FIG. 6.—Cavernous-type porosity in dolomite. 5×. Fuhrman's Boner B-9. 4,365–4,400 feet. Sec. 25, Blk. A-43, Andrews Co., Tex.

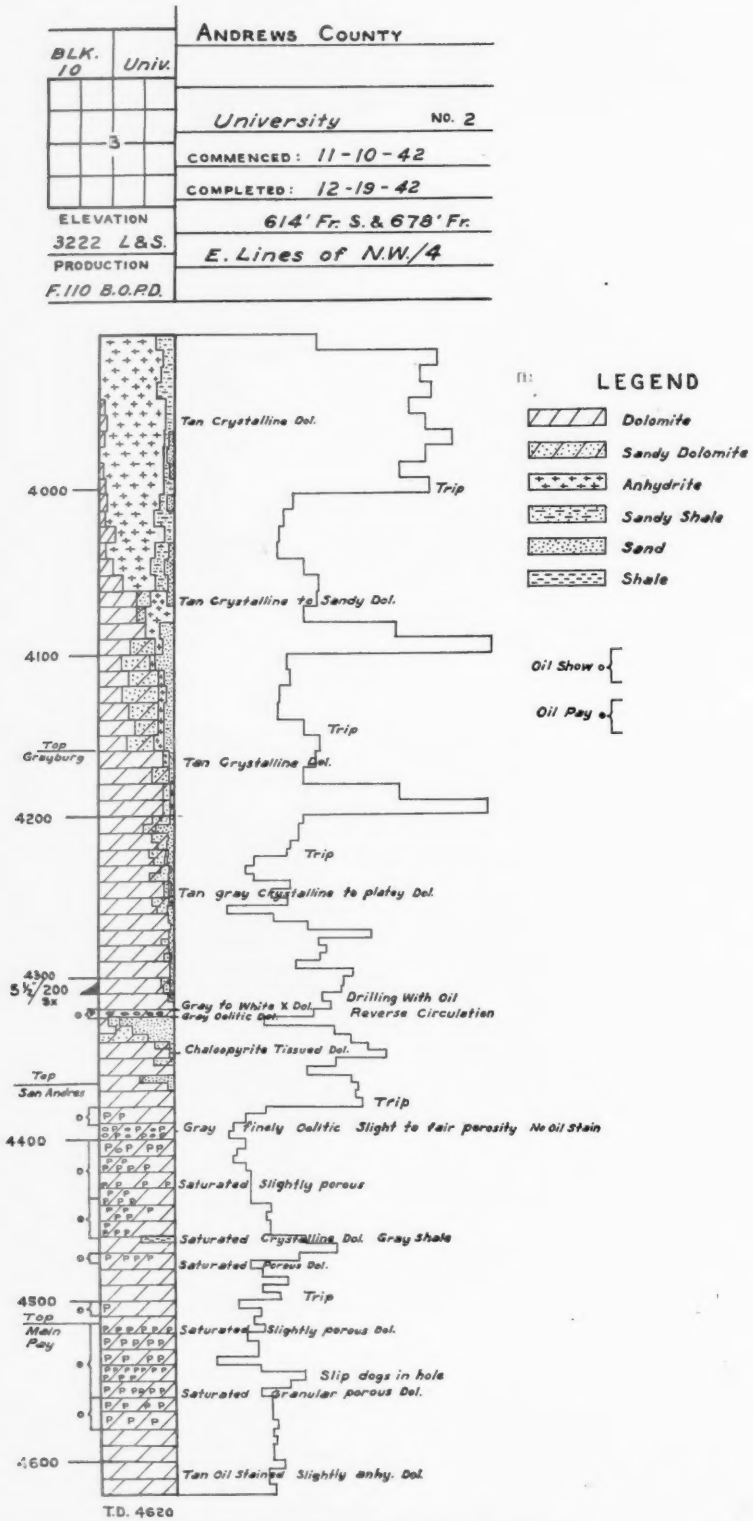


FIG. 7.—Type sample log of producing section.

tions or "cuts" of the samples should be large enough to be representative. Generally a tablespoonful should be the minimum.

EXAMINATION OF CUTTINGS SAMPLES

If the samples are properly prepared as outlined in the preceding section, they may be examined without further preparation. However, samples may not be washed properly on the rig and they must be rewashed before examination. This is most conveniently done in small sauce pans. The samples are agitated in water and the fine mud decanted; this process is repeated until the water is clear. Machines have been invented to help in this operation, but they are economical only where large numbers of samples must be washed. Drying the samples should be done as slowly as possible so as not to overheat and burn the sample. If a sample is only slightly dusty it may be prepared for examination by shaking over a screen of 100 mesh or finer. Some samples contain cavings which are ordinarily larger than the cuttings. These can be scraped off the top after agitation, and the residue of the sample examined. The same process helps to remove gel flake and other plugging materials added to the mud to control lost circulation. Iron particles in the samples can be removed by a magnet.

Samples may be examined while covered with water. This method brings out by differential refraction some of the qualities of the sample such as oölitic structures and anhydrite crystals which may be overlooked in dry samples. When examining the sample wet, it is not necessary to have them so clean as when examining them dry since a certain amount of washing may be done in the water in which the sample is examined. Dry examination is more convenient since it is not necessary to have a number of petri trays or watch glasses with which to examine the samples in water.

Cuttings samples ordinarily are examined under a binocular microscope of low power. The exact power used varies with the individual geologist and with the nature of the samples. The power should be high enough to see the essential structure and texture of the cuttings. Porosity coarse enough to have a permeability sufficient to make commercial oil production should be seen easily. Oölites, inclusions, and other sedimentary features should be clearly visible also. On the other hand, the microscope power should be low enough to permit examination of large numbers of samples without eye strain and should permit a field of view large enough to estimate percentages of the various constituents accurately with only a few changes in position of the sample. The powers that meet these requirements vary between 12 and 24. Higher powers are used for special purposes such as the description of minor features of microscopic fossils. For general use, however, in the oil industry it is not desirable to have a power higher than 24 since a very high power may give false impressions about the permeability and porosity of cuttings.

The illumination of the microscope field is important. In the past small incandescent lights which may be focused to give intense illumination have been

used widely. However, with the development of the fluorescent lighting tube, it has been found that the white light given by this tube is much superior to the yellowish light of the incandescent bulb. This is especially true when searching for oil stain in the cuttings, since the yellowish incandescent light commonly masks the light brown oil stain. Usually it is not practicable to focus the fluorescent tube so as to give intense light for high-power work. However, for the usual low-power examination, the fluorescent tube is very satisfactory. In examining samples for oil stain and saturation it may be desirable to use an ultraviolet light.

In examining well cuttings samples the geologist should endeavor to estimate as closely as possible the proportion of each rock type in the sample and to describe the lithologic characteristics of the rock that are essential to the correlation of the beds. In commercial work it is not practicable to give the analytical detail that may be desirable in purely scientific research. The geologist, nevertheless, should endeavor to make the description as complete as possible in the time available. Necessarily, the description should be more detailed on wildcat wells than on field wells and much more detailed in the pay sections than in the upper sections. In field wells it is permissible to omit descriptions of long sections of comparatively insignificant beds between key beds. The geologist should remember that it is much better to have too full a description than too meager a description. Experience has shown that full descriptions have saved much time and money, whereas meager descriptions have resulted in redescription of the cuttings several times. Nevertheless, some redescription can not be avoided; therefore, samples should be carefully preserved and indexed so that they will be available for future study.

There are two principal ways of describing samples. The first of these is the interpretative system, in which the geologist picks out the cuttings which he believes to be representative of the formation penetrated and describes the entire sample as composed of this rock. The rest of the sample is assumed to be cavings. This kind of description brings out formational changes and is of greatest value in areas where the various formations are of wide extent and relatively constant character, as in the Paleozoic of the Mid-Continent region. In areas of rapid lateral gradation in the lithologic character of formations, as in the Permian basin of West Texas, this method results in masking of lateral variations and misinterpretation of the nature of the stratigraphic column. This, of course, results in miscorrelation of the well logs.

In regions of pronounced lateral gradation it has been found that a second method of sample description is most satisfactory. This is the percentage description, where the geologist describes all material in the sample, disregarding obvious foreign substances and cavings. This system, though making it difficult to determine formational boundaries from the sample log, shows the gradations of the beds and often enables one to trace a horizon through different sedimentary facies.

Percentage of various constituents is estimated by the eye. It has been found

that experienced sample examiners, using good samples, will agree very closely on the percentages of constituents. However, with poor samples where some judgment must be exercised in disregarding obvious cavings, the value of the description is dependent on the judgment of the geologist who examines the samples. Mechanical counters or calculators, such as the integrating stage, have not been found to give enough additional accuracy to be worthwhile in ordinary work. Experienced sample examiners can describe 100–300 samples in an 8-hour day, according to the nature of the cuttings.[3]

The descriptions may be written out or plotted directly on a log strip. For many purposes, it is desirable to make written descriptions, since the logs can be

TABLE II

EXAMPLE OF SAMPLE-DESCRIPTION FORM

OPERATOR_____ NO._____ LEASE_____ COUNTY_____

SECTION BLOCK LEAGUE SURVEY

LABOR_____ TWP._____ RANGE_____ FOOTAGE_____

ELEVATION_____ T.D._____ DATE_____ EXAMINED BY_____

DEPTH		LIME OR DOLOMITE	ANHY.				NON RED SHALE		RED SHALE	RED SS.	GRAY SS.		CHERT
FROM	TO		%	LITH.			%	LITH.					

plotted in several places at the same time and a record is kept which is not subject to destructive wear as is the plotted log which is used constantly in the field and laboratory. A type of description form is included (Table II). In addition to the constituents shown on this form, others may be specified according to the nature of stratigraphic sections in the area worked. Pyrite and differently colored shales will be the most likely additions. In areas where sand production is important, separate columns for porosity and saturation in sandstone may be desirable.

Color of the rock fragments in cuttings samples is a very important attribute. At present there is a wide variation in the descriptions of color by subsurface

[3] A full description of sample examination as applied to stratigraphic work is given by L. H. Lukert, *Oil and Gas Jour.* (June 17, 1937), pp. 49–51.

geologists. The same rock may be described as tan by one and brown or gray by another. It is desirable in any organization attempting to start sample examination work to standardize some color scheme, possibly that being developed by the inter-society committee.[4]

Size of particles in dolomites and limestones is another matter on which subsurface geologists vary. The following table gives tentative scale of crystal sizes which was developed by the West Texas Geological Society several years ago. It would be to the advantage of anyone undertaking sample description for the first time to adopt a scale with appropriate abbreviations for the sample-description sheets.[5]

TABLE III

TENTATIVE SCALE OF CRYSTAL SIZES IN DOLOMITES AND LIMESTONES

Descriptive Adjectives	*Crystal Diameter*
1. Mat	Invisible
2. Microcrystalline	Less than 10 mm.
a. Cryptocrystalline	Less than 0.02 mm.
b. Finely crystalline	0.02 to 0.1 mm.
c. Mediocrystalline	0.1 to 2.0 mm.
d. Coarsely crystalline	2.0 to 10 mm.
3. Megacrystalline	

DEFINITIONS

Mat.—Compact, exceptionally homogeneous; having a dull but even surface under low-power binocular microscope; resembling limestones used in lithography; as, a *mat* limestone, a *mat* dolomite

Microcrystalline.—Having crystals less than 10 mm. long; having crystals small enough to be viewed under low-power binocular microscope

Cryptocrystalline.—Indistinctly crystalline; showing very small, indistinct crystal faces; composed of crystals too small to be measured under low-power binocular microscope

Megacrystalline.—Having crystals 10 mm. or more in length; having crystals too large to be readily discernible under low-power binocular microscope.

POROSITY, PERMEABILITY, AND OIL STAIN

Description of the porosity, permeability, and oil stain of cuttings samples is one of the most important parts of the sample examiner's work. In sandstone, the porosity is determined by the size of the grain, the sorting, and the amount of the cement present. The grain size should be described by some standard scale such as Wentworth's[6] or Alling's.[7] The sorting is dependent on the proportion of fine minerals present, such as silt or shale, or the proportion of large grains, such as large frosted quartz grains commonly found in the Whitehorse section of the Permian basin. The amount of cement also largely determines the porosity which is at a maximum in free unconsolidated sands and minimum in quartzite. The permeability is largely determined in the same manner as porosity, but here the size of grain and the sorting are most important.

[4] Ronald K. DeFord, "Rock Color Chart for Field Geologists," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 10 (October, 1947), pp. 1903–04.

[5] A more elaborate scale is advocated by Ronald K. DeFord, "Grain Size in Carbonate Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 10 (November, 1946), pp. 1921–28.

[6] C. K. Wentworth, "A Scale of Grade and Class Terms for Clastic Sediments," *Jour. Geol.*, Vol. 30 (1922), pp. 377–92.

[7] H. L. Alling, "A Metric Grade Scale for Sedimentary Rocks," *Jour. Geol.*, Vol. 51 (1943), pp. 259–69.

Oil stain and odor are very important and much experience on the part of the sample examiner is required to estimate these accurately. Dry gas will not stain sandstone, but wet gas may show a very light tan stain. Oil is commonly darker, but very high-gravity oil shows no more stain than the gas. Porous sand, containing no stain whatsoever may be suspected of carrying water. In examining samples of oil stain, it is very convenient to have a fluoroscope. This may detect very light stains of high-gravity oil which are not obvious in ordinary light. Best results in detection of oil stains are obtained with mercury vapor lamps emitting light, with wave lengths ranging from 3,300–3,800 Angstrom units. Lamps giving light of shorter wave lengths, such as the quartz tube, cause fluorescence of oil, but also cause much mineral fluorescence in the sample which may confuse the observer.

USE OF CUTTINGS DESCRIPTIONS IN STUDY OF LIMESTONE RESERVOIRS

Limestones and dolomites form important oil reservoirs, and cuttings descriptions furnish one of the chief sources of information concerning them. There are two chief types of porosity in these rocks. The first is intergranular porosity which consists of openings between the crystals, oölites, or other discrete particles of the rock which in its geometry is similar to sandstone porosity. The second is fracture porosity (or foramenular porosity of Bulnes and Fitting[8]) which consists of large openings through otherwise solid masses, such as fractures and vugs.

The intergranular porosity is easily observed under the binocular microscope where the tiny openings may commonly be seen connected with each other. The larger openings are not ordinarily visible in their entirety under the microscope but are indicated by irregular surfaces lined by crystals which have been formed in a comparatively large cavity. These large openings are much more difficult to detect than the smaller pores and ordinarily they have gone unnoticed unless indicated by the drilling-time or the manner of drilling. Permeability in the fractures or foramenular porosity is almost impossible to determine under the microscope since there is no means of knowing how far apart the walls of the large openings originally were.

Permeability in intergranular porosity can be estimated qualitatively by noticing the size of the pores and their apparent interconnection. In general, the larger the pores the higher the permeability. The converse, however, is not always true. Some dolomites showing very fine porosity are shown by core analysis to be surprisingly permeable. However, one type of porosity is non-permeable almost without exception. This is called pin-point porosity and consists of small isolated holes. Some of these holes contain small amounts of asphaltic material and even may contain live oil and gas, but commercial production is not developed from them. So far, no quantitative results about porosity and permeability have been

[8] A. C. Bulnes, and R. U. Fitting, Jr., "An Introductory Discussion of Reservoir Performance of Limestone Formations," *Petroleum Development and Technology, 1945, Petroleum Division, Trans. Amer. Inst. Min. Met. Eng.*, Vol. 160, pp. 181–201.

obtained from ordinary cuttings. However, the coarser reverse circulation cuttings have been analyzed for porosity and permeability with favorable results.

An interesting method of reproducing and visualizing these pore spaces is presented by Nuss and Whitney,[9] who impregnated limestones with plastic and then dissolved the limestone with acid, leaving a model of the porosity as a residue.

Oil and gas stains are ordinarily readily detectable in limestones and dolomites. The heavy sour oils, as found in the Upper Permian, leave a dark brown stain which is unmistakable. Lighter oils of the Lower Permian rocks show good stains while the very light oils found in the Lower Paleozoic strata leave an extremely light stain which is difficult to detect under incandescent light, but may be seen in white or ultra-violet light. Since most gases carry a small amount of light oil with them they will show slight stains in limestones. Gas-oil contacts commonly can be recognized accurately by the darkening of the stain at the top of the oil column. Water may be indicated by lightening of the stain and black asphaltic residues in the samples. Many dolomites have a characteristic sheen on crystal faces within the water zone. However, a well oil-stained section may produce water upon test. This may be attributed to later movement of the structure which causes shifting of the water table.

In concluding the discussion of cuttings description, it should be said that no rigid rules can be given for guidance in describing samples. Each geological province and each geological organization have their own problems which must be worked out individually. Since the stratigraphic sections penetrated by wells are as varied as those on the surface, there can be no substitute for experience and judgment on the part of the geologist. Description of samples should never be allowed to degenerate into a mere mechanical process. The better the geological background of the person examining samples, the better will be the description.

PLOTTING

After the description of the samples is made, it must be plotted in graphic form to make the information easily available for correlation and study. It is usual to plot this material on a narrow strip of heavy paper or cardboard so that a large number of logs can be laid out to compare and correlate the sections. A 3-inch width has been found to be most convenient for this purpose. Upon this 3-inch strip the lithologic characteristics are plotted on a column $\frac{1}{2}$–$\frac{3}{4}$ inch wide with a vertical scale of 1 inch equals 100 feet. On this column each 10 feet (1/10th inch) is marked so as to facilitate plotting. The rest of the log strip is used for notes on lithologic characteristics that are not easily plotted as symbols. It has been found in plotting the lithologic characteristics that strong contrasting colors facilitate correlation and comparison of the sections. While no standard system of symbols has been adopted, the following colors are widely used.

[9] W. F. Nuss, and R. L. Whitney, "Technique for Reproducing Rock Pore Space," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 11 (November, 1947), pp. 2044–49.

Light blue = Calcareous limestone
Dark blue = Dolomite
Red = Red shale
Gray = Gray shale
Yellow = Sandstone
Green = Salt
Purple = Anhydrite

Other colors may be added for local necessities. It has been found very helpful also to plot the drilling time next to the lithologic column on the log strip. In the case of mechanically taken drilling time, a copy of the graph is plotted; with manually taken drilling time, the plotting is done as bar graphs—the common scale being 1 inch equals 100 minutes of drilling time.

Porosity and oil stain in the samples are indicated by symbols on either side of the lithologic column. These symbols may be either in ink or in suitable colors. It is very helpful to make some distinction as to probable gas or water stain even though these fluids can not be differentiated certainly from cutting examination. Sharp changes in lithologic character should be indicated plainly on the plotted log. This usually is done best by having the geologist who examined the samples check the plotted log and indicate where he believes the formation boundaries should be, because their exact position is commonly difficult to determine from the written description alone.

All tests and showings should be indicated on the margin of the log strip. These should include all drill-stem tests in rotary wells, and amount and kind of fluid in cable-tool holes. It is also helpful to indicate any swabbing tests taken, the acid used, amount of nitroglycerine used and section shot, and perforations in the casing. Casing seats should be indicated on the margin of the log with a notation of the diameter of the casing and the amount of cement used in setting the casing. Total depth, location, and initial production of the well should be shown in the heading of the log strip.

USING SAMPLE LOGS

The first use of these sample logs is stratigraphic correlation, by laying the logs alongside each other and matching bed for bed as far as possible. In doing this the geologist must keep in mind probable lateral gradation, probable contamination of samples, and probable changes in intervals from one horizon to another. Care should be taken not to correlate over any greater distance than is necessary. For correlation purposes one tries to select wells close together and extending as far as possible along the lithologic strike. This information can be used for construction of cross sections[10] and stereograms[11] to show stratigraphy.

After these correlations are made and the stratigraphic section established, zones can be found whose tops will make good index beds for structural mapping.

[10] John M. Hills, "Rhythm of Permian Seas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 2 (February, 1942), pp. 217–55.

[11] Frank E. Lewis, "Position of San Andres Group, West Texas and New Mexico," *ibid.*, Vol. 25, No. 1 (January, 1941), pp. 73, footnote 1.

In selecting such horizons one must consider that the depths of samples from which the logs were made may not have been corrected for the lag in coming to the surface. Therefore, especially in zones far below the surface, the geologist must allow for this correction or must correct his datum points by the drilling time if available.

Another important use of sample logs and descriptions is in the analysis and evaluation of any pay zone, especially in limestone reservoirs. This may be done by tabulating the pay sections in columns, as shown in Table IV. The first column shows the depth of each sample in the pay section, the second column shows the net feet of pay which is the percentage of porosity and saturated material in the sample times the sample interval, and the next columns give the quality of the

TABLE IV

DETAILED RECOVERY ESTIMATE, UNIVERSITY WELL NO. 2, ANDREWS COUNTY, TEXAS

Depth in Feet	*Remarks*	*Net Feet Slight Porosity*	*Net Feet Fair Porosity*	*Net Feet Medium Porosity*	*Net Feet Good Porosity*	*Acre-Foot Recovery*	*Recovery Per Acre (Barrels)*
4380–85	Stained	1				75	75
90	Stained	1				75	75
4400–05	Sat. v. sl. por.	2				50	100
10	Sat. oolitic	3				100	300
15	Sat. isolated por.	3				50	150
20	Sat. gran. v. Sl. por.	4				50	200
25–30	Sat. v. sl. por.	4				50	200
35	Sat. v. sl. por.	1				50	50
40	Sat. v. sl. por.	2				50	100
45–50	Sat. sl. por.	1				100	100
55–60	Sat. gran.	2				125	250
65–75	Sat.	4				150	300
4500–05	Stained	1				75	75
10	Sat.	1				100	100
15–20	Sat.	5				75	375
25	Sat.	5				75	375
30	Sat. gran.	5				100	500
35	Sat. gran.	3				100	300
40	V. sl. f. por.	5				40	200
45	Sat. gran.	5				100	500
50	Sat. cryst. sl. gran.	3				50	150
55	Sat. cryst.	1	2			200	600
60	Sat. gran.	4				150	600
65	Sat. gran.	1	1			200	200
		65	3			Total	5875

pay which is the geologist's estimate of the porosity and permeability in a qualitative manner, such as slight, fair, medium, and good. The next column shows the probable acre-foot recovery from the pay. This figure is derived from core analyses in this field if available or from sample descriptions of pay in fields where the ultimate recovery is reasonably well established from past production. The next column in the analysis is the recovery per acre, which is the acre-foot recovery times the net feet of pay. This gives the recovery per acre for each sample interval. The total of this column gives the recovery per acre for the well. Of course, this is a volumetric estimate of the recoverable oil from any well, and since limestone reservoirs are commonly heterogeneous in their composition, this recovery estimate falls within wide limits of error. Well spacing, of course, has a considerable effect on ultimate recovery. Thus, if the acre-foot recovery figures

are derived from wells differing in spacing from the well under analysis, due allowance must be made for this difference in spacing. Generally, it is found that this volumetric estimation is somewhat above an estimate made from pressure decline or production decline curves, and allowances should be made. In spite of its imperfections, this method of valuation is the only one available in many fields in which cuttings samples have been kept but no other type of reservoir information is available.

A somewhat similar method may be used in the case of sandstone reservoirs. However, since sandstone reservoirs are much more uniform in their porosity and permeability it is commonly possible to assign an acre-foot recovery for an entire field and to obtain the ultimate recovery by multiplication of the net pay sand thickness in any well by the acre-foot recovery, rendering detailed pay analysis unnecessary.

Logs of cuttings samples are also very useful in studying the characteristics of limestone reservoirs. They give some idea of volume and relative permeability of lenticular pay zones. They are a useful supplement to any coring program undertaken as part of a reservoir study. It is often possible to select gas-oil contacts from cutting logs so as to select points for plug-back or for packer settings in remedial work.

SUMMARY

Samples of well cuttings can be taken from both cable-tool and rotary holes in such a manner that the nature of the formations penetrated can be determined accurately. These samples can be described by a geologist and the description plotted so as to give a graphic section of the formations encountered in the well. These sections can be correlated to give a picture of the regional stratigraphy. From the sections, index beds can be selected for use in structural contouring.

From the sample descriptions, volumetric estimates of ultimate well yield can be made, reservoir study facilitated, and well remedial work guided.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 1 (JANUARY, 1949), PP. 92-98, 3 FIGS., 1 CHART.

OSCILLATION CHART[1]

MERLE C. ISRAELSKY[2]
Pasadena, California

ABSTRACT

A chart is presented, based on the foraminiferal content of shaker samples ranging from 6,000 to 11,760 feet from a well in the Lirette field, Terrebonne Parish, Louisiana. It is contended that the chart shows relative changes in depth of water at this geographic position during the deposition of the "Miocene" penetrated by the drill. The method of building the chart, the reasoning behind the method, its possible uses and limitations are discussed.

INTRODUCTION

Several years ago the writer studied samples from the four wells drilled in the DeLarge gas field, Terrebonne Parish, Louisiana. It was concluded that three of the wells could be correlated throughout the penetrated marine "Miocene" section, and that the fourth could be correlated in part. From previous experience in the parish, the opinion had been reached that except for very local work, the use of the upper range of fossils for correlation was without great value, because the tops varied greatly in stratigraphic position as samples were examined along the depositional dip. While this is of course true in sediments of any age, here the changes were so strikingly more rapid than in older beds of the Gulf Coast in which "tops" had been rather successfully used, that the method was abandoned.[3]

Check-listing was the method adopted, and species floods (large numbers of species) were used for correlation. It was concluded that two of the three floods recognized carried through all four wells and the third through three of them. However, the writer's conclusions were not identical with those of other paleontologists and geologists familiar with the area. Furthermore, the other workers disagreed among themselves.

Biologists have long been aware that ecologic control exists for marine organisms. Nevertheless, the first observed plotting of the percentages of various genera of foraminifera in relation to the depth of water in which they occur was that by S. W. Lowman,[4] who in 1941 prepared a number of profiles extending into the Gulf of Mexico. It was not until 1947 that several of these profiles were

[1] Manuscript received, September 18, 1948.

[2] Division of the Geological Sciences, California Institute of Technology.

To Marcus A. Hanna who edited the chart, A. O. Woodford and E. C. Buffington, for reading the manuscript and offering pungent suggestion, grateful acknowledgment is offered.

Clarence L. Moody has graciously given assistance beyond the call of editorial duty.

To Walter H. Spears, vice-president of the Union Producing Company, Shreveport, Louisiana, appreciation is expressed for his readily granted permission to publish these data.

A pleasant and stimulating association with Marcus A. Hanna, S. W. Lowman, A. R. Mornhinveg, and Lloyd Pyeatt has no doubt helped in formulating these ideas.

[3] Alva C. Ellisor, "Subsurface Miocene of Southern Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 3 (March, 1940), pp. 435–75, 11 figs., 6 pls. Miss Ellisor's paper typifies this technique and still provides the framework for the stratigraphy of the "Miocene" of South Louisiana.

[4] S. W. Lowman, "Recent Clastic Sediments Project," *Amer. Assoc. Petrol. Geol. Research Com. 1946–47, Project 5* (1947).

published. Lowman made available prints of his charts in 1941, and while they were highly informative, their application to subsurface problems continued to be baffling.

Late in 1945 it was postulated that if the foraminifera could be arranged in order of their depositional depth significance, an oscillation chart might be constructed showing relative changes in depth of water at time of deposition within a well or surface column. In 1947 such a chart was finally constructed for one well.

The well chosen was one in the Lirette field, where control was sufficient to be sure that the hole studied had no marked structural complications. It was hoped to compare eventually this well with one at DeLarge, but an opportunity has not materialized.

METHOD OF CHART CONSTRUCTION

Samples of cuttings were available at 30-foot intervals, with a few exceptions. For each interval a sample 4 cubic inches in volume was thoroughly broken down and in most cases a full recovery of foraminifera was achieved. A count was taken of the number of specimens of each species, or closely related group of species in each sample cutting. Separate percentage calculations were made for the benthonic (bottom-dwelling) and the pelagic (floating) assemblages, as the latter are not directly controlled by bottom conditions. These species (or group of species) amounting to less than 0.5 per cent were eliminated and recalculations made for the remainder. Where there were less than 20 benthonic specimens present, no percentages were calculated.

To determine the relative depth significance of the foraminiferal species the percentage of each species (or group of species) in each sample was first plotted against that of *Rotalia beccarii*, considered to be of brackish habitat, and then against *Uvigerina spp.*, considered a typically deeper open-water element. All those species attaining a notable percentage of abundance agreed as to sequence on the two plots. Those which did not agree were placed in the sequence by aid of Lowman's charts, experience, and perhaps instinct. These non-conformists are of such small percentages that they would not materially affect the chart, wherever placed. The species (or groups of species) are numbered in order of their apparent peak percentage appearance from shallower to deeper water. The numbers are substituted for fossil names on the chart. A first plot was made, including the arenaceous with the calcareous benthonic forms in a single column. When arenaceous forms occurred in epidemic numbers, they shifted the positions of the species on the chart to an excessive degree. As they probably are controlled in occurrence somewhat by factors that differ from those which control the calcareous forms, it was concluded that the two types of benthonic foraminifera should be separately charted. Calculations were then made for each type, and these, together

[5] Alva C. Ellisor, *op. cit.*

with the pelagic species which are represented by letters *A* to *D* were placed on the final chart, each horizontal row indicating 100 per cent of the particular type of foraminifera.

The narrow columns on either side of the arenaceous column give ratios of the calcareous to the arenaceous benthonic foraminifera, and of the benthonic to the pelagic foraminifera.

The rectangular blocks and numbers at the left of the calcareous column, at

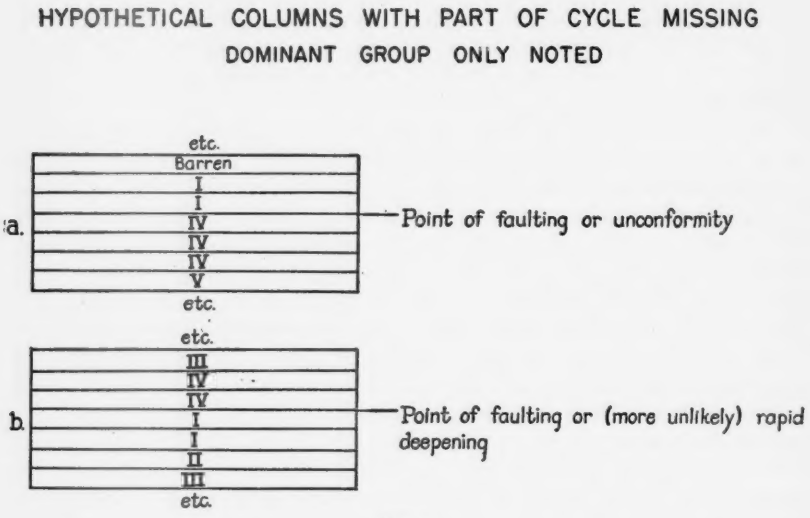


FIG. 1

the right of the arenaceous column, and at the right of the pelagic column indicate specimen counts for the three groups.

Specific names are taken from Ellisor's paper,[5] which may also be referred to for lithologic descriptions.

INTERPRETATION OF CHART

The benthonic calcareous foraminifera are considered the more delicate depth indicators. As the species numbers shift to the left, the phenomenon is interpreted to indicate deepening. The shifting of species numbers to the right is considered to denote shallowing (Fig. 2).

The calcareous species are somewhat arbitrarily grouped. For our purposes, group I may be considered as a brackish assemblage, not necessarily in shallower water than II, but in waters of less than normal Gulf salinity. Group II may be called the beach assemblage, III probably represents the seaweed zone assemblage, and IV and V are successively deeper assemblages. If each of these

OSCILLATIO

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SEC. 23 - T. I

LIRETTE

TERREBONNE PARI

(CHARTED BY M. C. ISRAEL

BENTHONIC

Numbers moving to Left = Water deepening
Numbers moving to Right = Water shallowing

CALCAREOUS
By Groups

CALCAREOUS

Specimen count

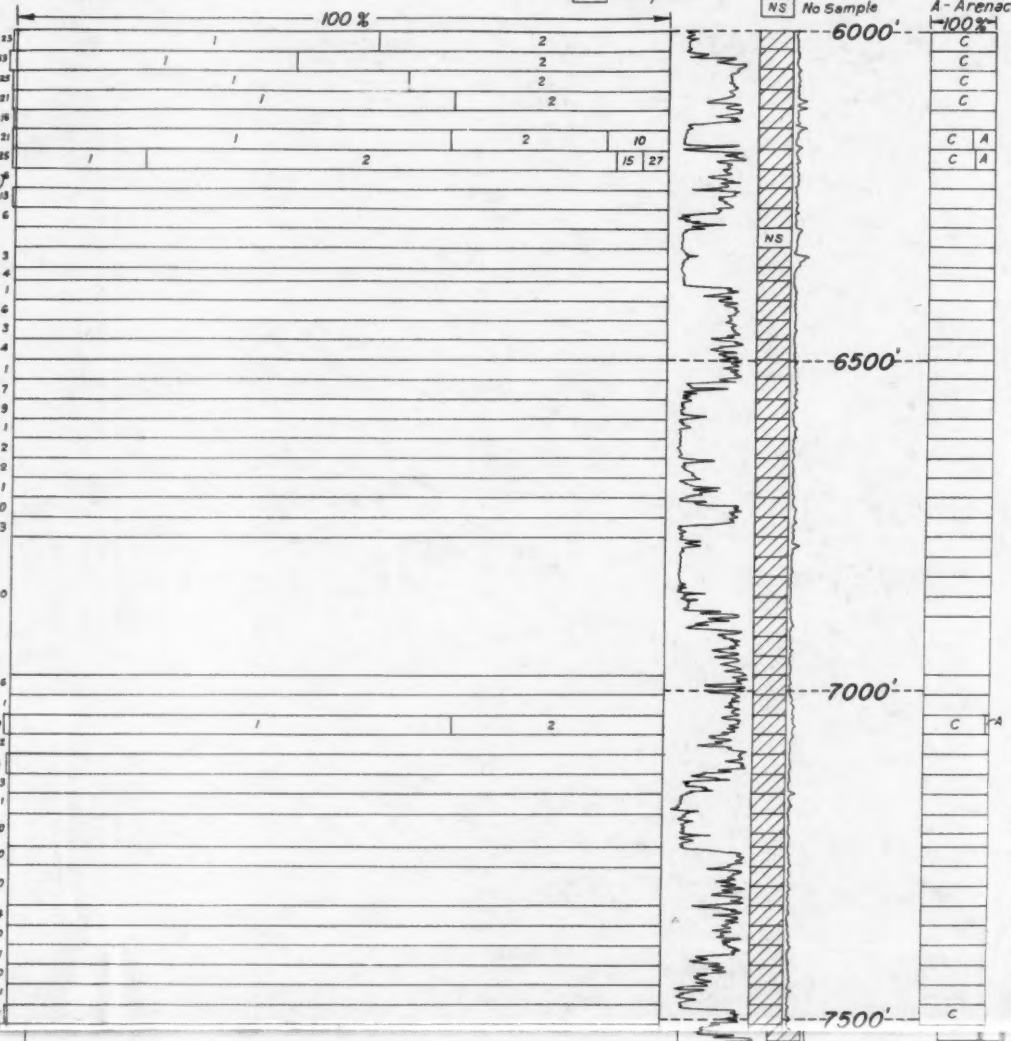
Cmt Mostly Cement

Sample

NS No Sample

C - Calcareou

A - Arenaceo



CALCAREOUS

GROUP I

1. Rotalia beccarii (Linne)
2. Elphidium spp.

GROUP II

3. Pulvinulinella spp.
4. Eponides mansfieldi Cushman
7. Miliolids (mostly Quinqueloculina)
9. Virgulinella spp.
10. Nonion spp (porcellaneous type)
11. Nonionella spp.
12. Buliminella curta Cushman
13. Virgulina spp.
14. Reussella spinulosa (Reuss)

GROUP III

15. Discorbis spp.
16. Eponides antillarum (d'Orbigny)
17. Cibicides concentricus (Cushman) and similar forms

GROUP IV

18. Cristellaria spp. (beaded forms)
19. Amphistegina lessonii d'Orbigny
20. Cristellaria spp (smooth forms)
21. Cibicides carsteni Cushman and Ellisor

GROUP V

22. Uvigerina spp.
23. Cancris sagra (d'Orbigny)
24. Massilina spp.
25. Lagena sp.
26. Siphonina jacksonensis Cushman and Applin var. limbosa Cushman
27. Bolivina spp.
34. Gyroidina scalata Garrett
35. Gyroidina sp. (soldani type)
36. Dentalina spp.
37. Cassidulina spp. and Cassidulinoides spp.

36. Dentalina spp.
37. Cassidulina spp. and Cassidulinoides spp.

ATION CHART

N FORAMINIFERA IN

CO. ~ DELTA SECURITIES NO. 1

23 - T. 19S. - R. 19E.

RETTE FIELD

E PARISH, LOUISIANA

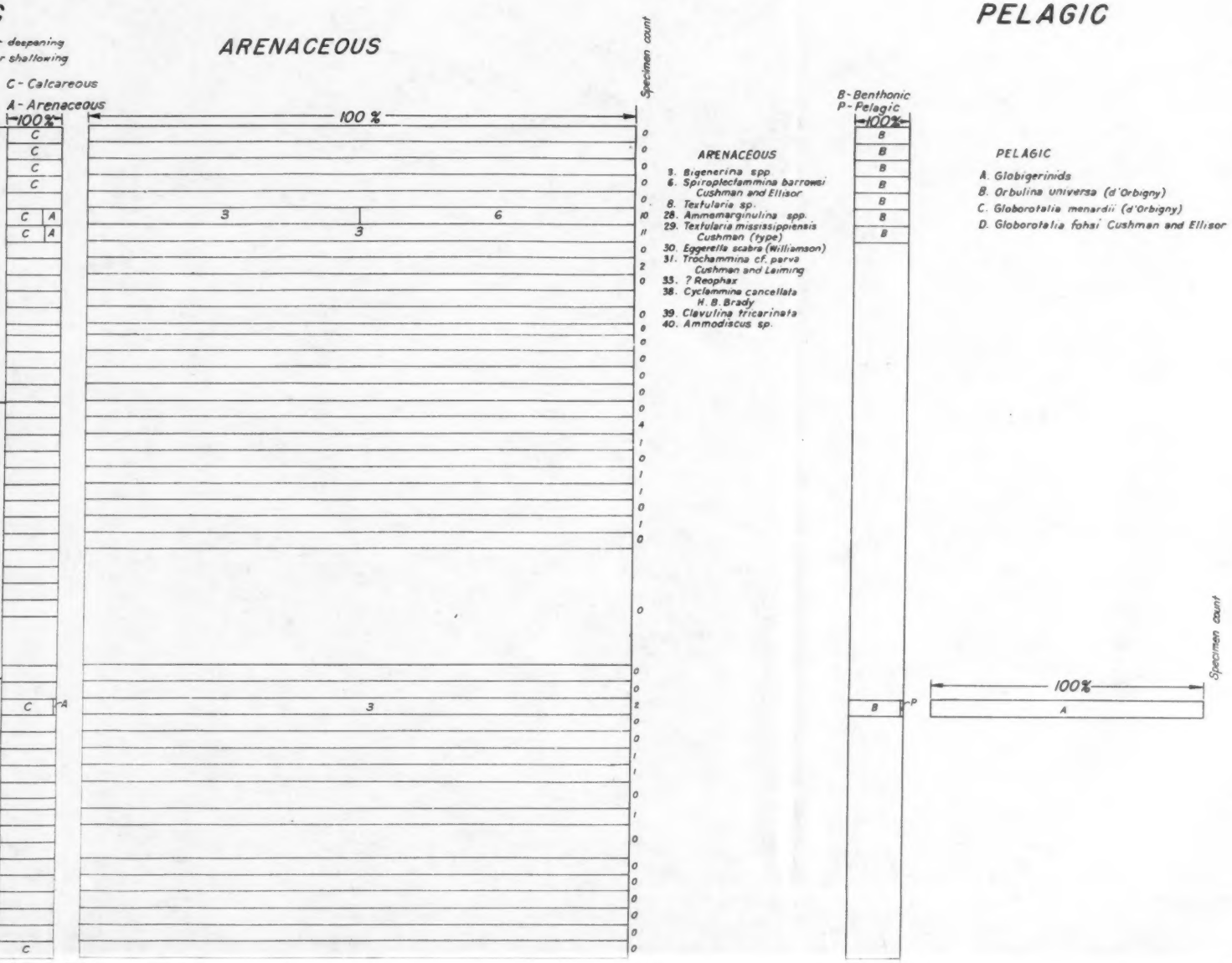
C. ISRAELSKY — JAN. 19, 1948)

C

- deepening
- shallowing

C - Calcareous

A - Arenaceous

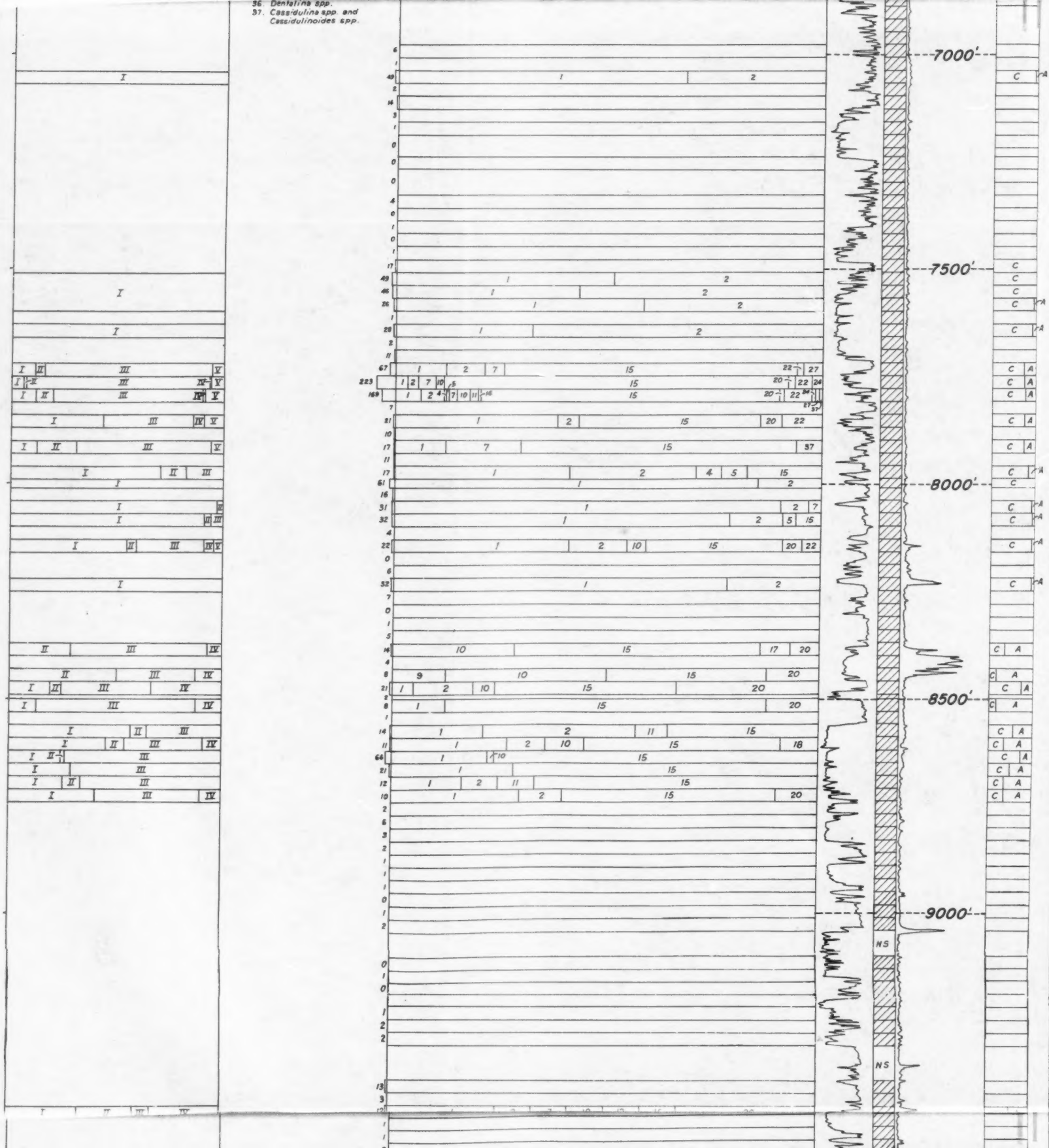
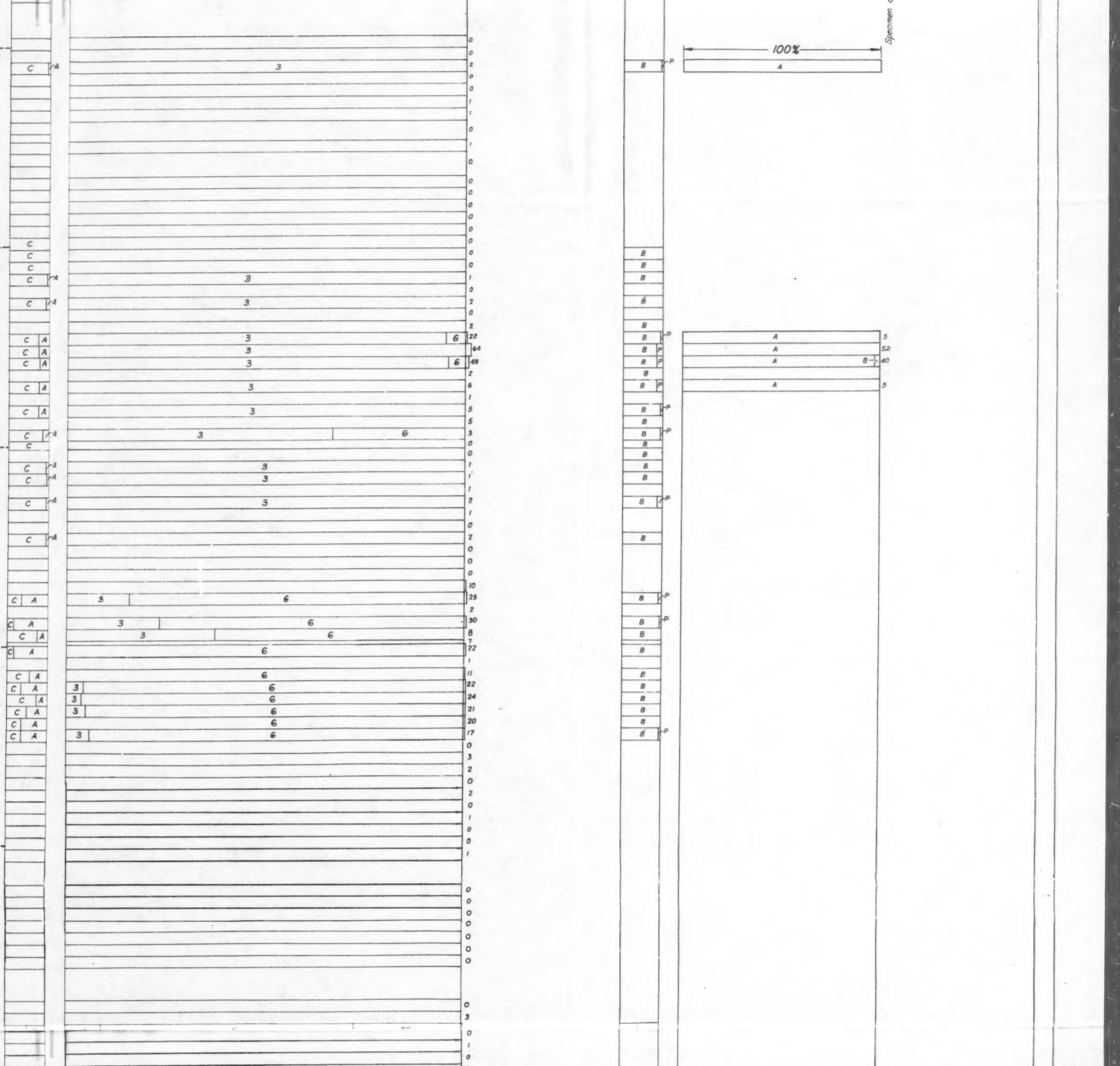


ARENACEOUS

1. Bigenerina spp.
6. Spiroplectammina barrowsi Cushman and Ellisor
8. Textularia sp.
28. Ammemarginulina spp.
29. Textularia mississippiensis Cushman (type)
30. Eggerella scabra (Williamson)
31. Trochammina cf. parva Cushman and Laiming
33. ? Reophax
38. Cyclammina cancellata H. B. Brady
39. Clavulina tricarinata
40. Ammodiscus sp.

PELAGIC

A. Globigerinids
B. Orbulina universa (d'Orbigny)
C. Globorotalia menardii (d'Orbigny)
D. Globorotalia fohsi Cushman and Ellisor

36. *Dentalina* spp.
37. *Cassidulina* spp. and *Cassidulinoides* spp.


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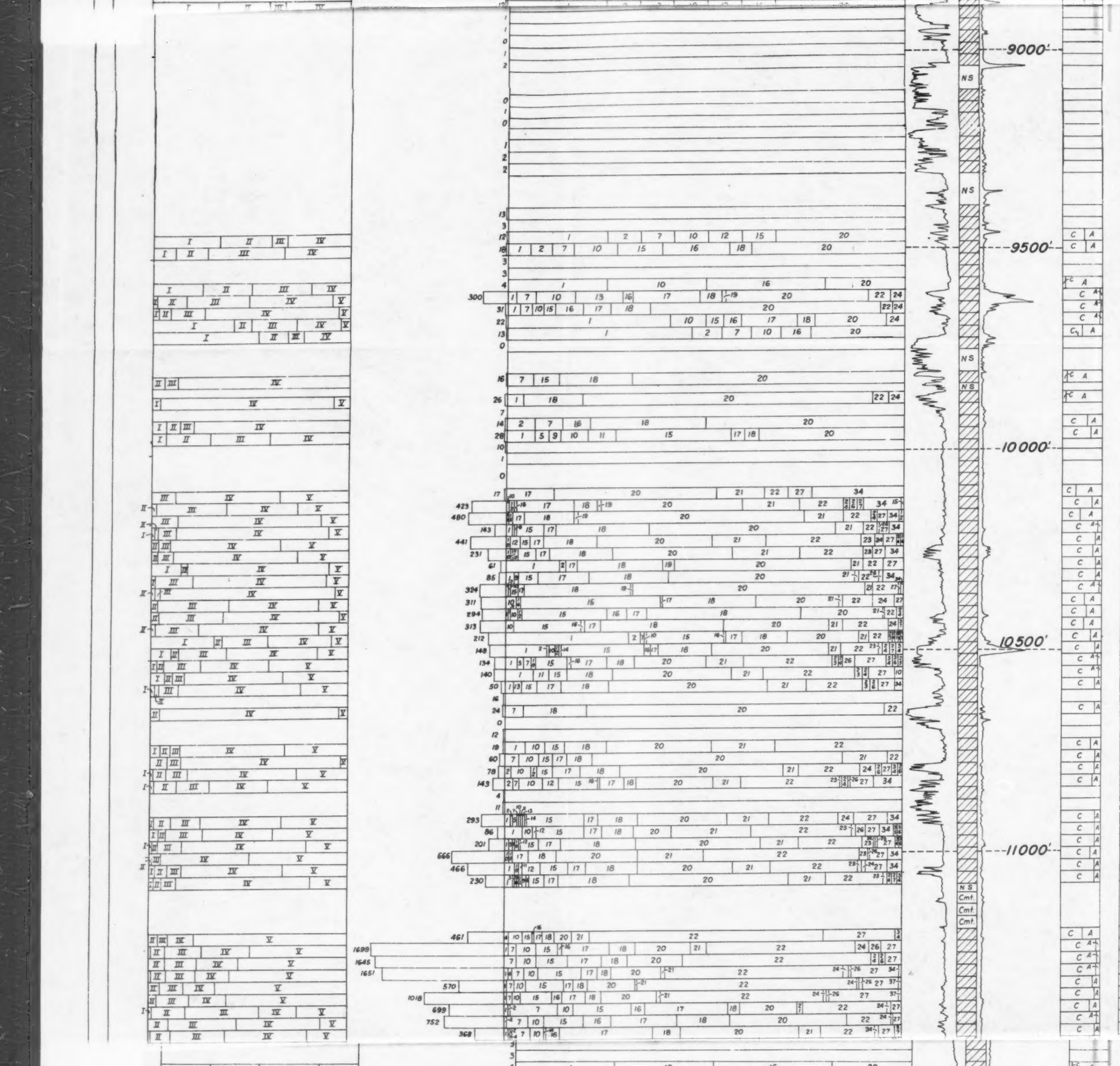
Specimen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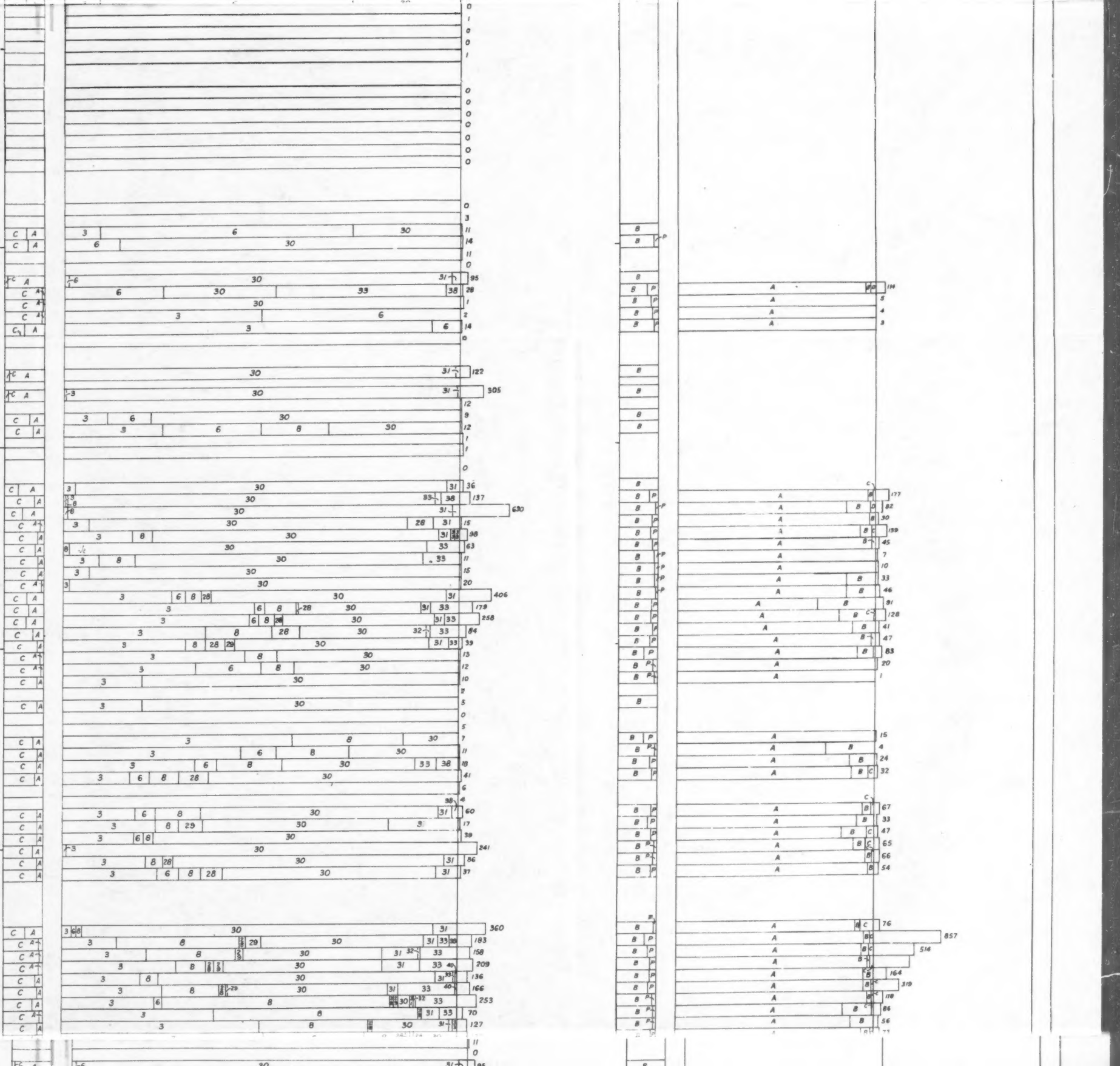
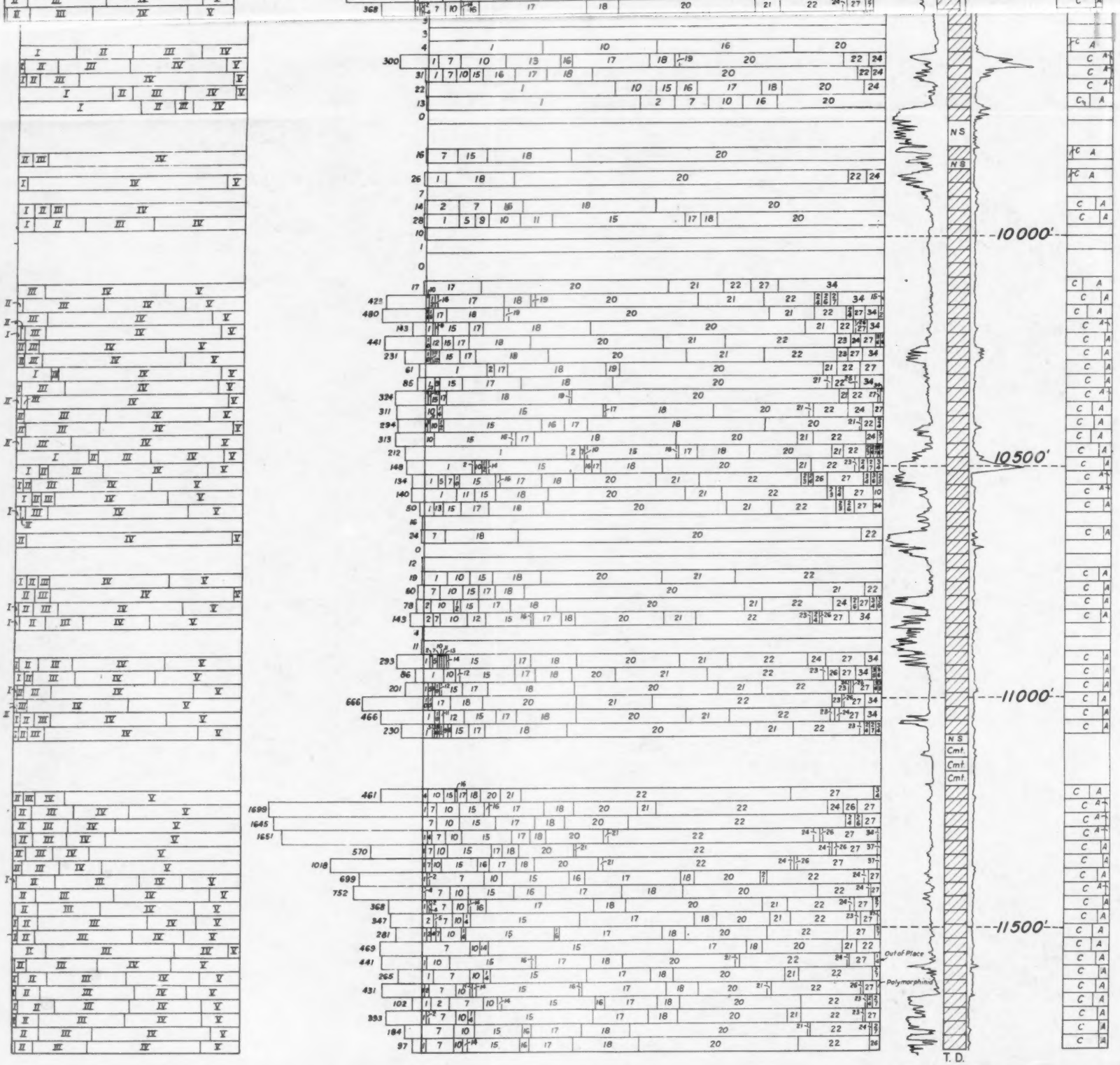
10000'
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NS
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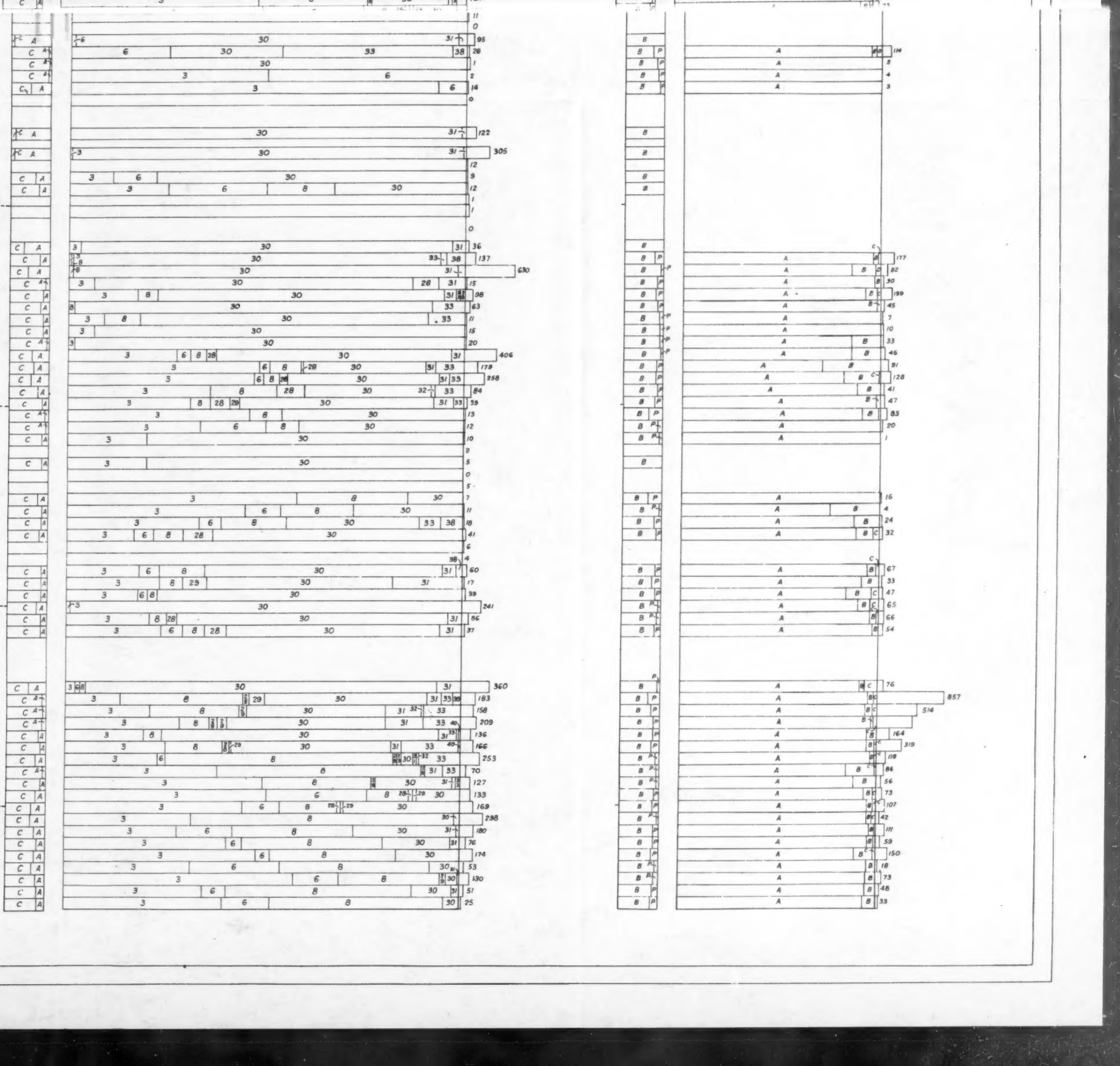
Cmt.
Out of Place
Polymorphina
T. D.



groups is differently colored on the chart, oscillations may be readily discerned. Oscillations as indicated by the arenaceous column were found to correspond qualitatively with those indicated by the calcareous column. If arenaceous species numbers are colored as they would fall if included with the calcareous groups,

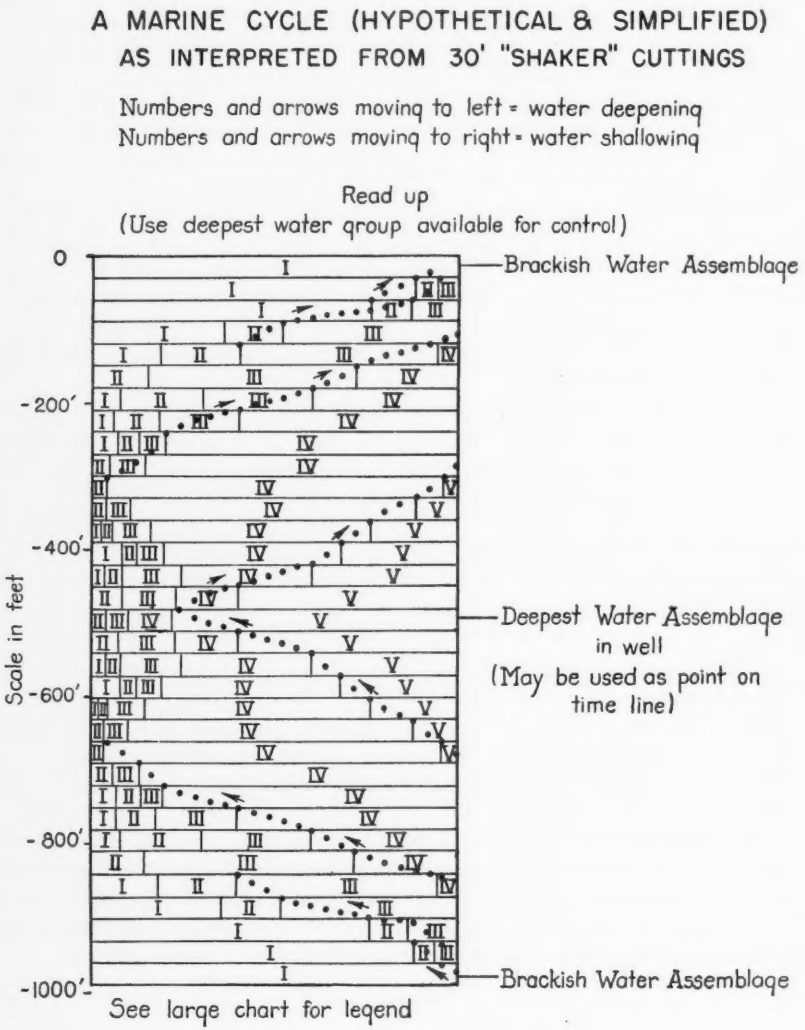

A MARINE CYCLE (HYPOTHETICAL & SIMPLIFIED)
AS INTERPRETED FROM 30' "SHAKER" CUTTINGS
Numbers and arrows moving to left = water deepening
Numbers and arrows moving to right = water shallowing
Read up
(Use deepest water group available for control)
0
-200'
-400'
-600'
-800'
-1000'
Scale in feet
Brackish Water Assemblage
Deepest Water Assemblage in well
(May be used as point on time line)
Brackish Water Assemblage
See large chart for legend

FIG. 2

that is, color 3 as I, 6 and 8 as II, the remainder as V, since none happens to reach peak percentages within the range of III and IV, the similarity is clearly shown.

The pelagic column shows no close relationship to the benthonic columns. Globigerinids were not broken into species, as the young are difficult to recognize, even generically. All that can be said definitely is that *Orbulina universa* remains well off shore and in Lowman's charts it is indicated that *Globorotalia* reach a more shoreward position than *Orbulina*, while some globigerinids are carried by the longshore currents. This present condition seems paralleled in the Miocene. From the chart it may be interpreted that the current carrying *Orbulina* swung in and out over the Lirette area without much control by the depth of bottom.

LIMITATIONS OF SAMPLES

As noted in the introduction, the samples were cuttings. It is regrettable they were shaker cuttings, meaning that they formed only that portion of the well returns which was retained on a screen. There seems to be no standard screen. It follows that any microfossils loosened from their matrices, clay or sandstone, were lost. A plot was made of the amount of sandstone or sand left after washing, but it bore so little resemblance to what the electric log indicates, that it was not included on the chart.

As a result of the collection methods, we may conclude that sand-bottom species are not fairly represented, and that we are dealing almost entirely with fossils derived from claystones. Similarly we probably lack any representation from rapidly slaking claystones, including the marly or bentonitic varieties.

It is obvious that cores would provide a truer picture. Opportunity is taken to reiterate that full cuttings, those taken before well returns pass over the shaker, would also give more desirable results. This holds just as firmly for other methods of correlation.

POSSIBLE IMPROVEMENT OF CHART

Rotalia beccarii is readily debouched from its favorite habitat in brackish bays and lagoons into the open sea by tidal scour, and perhaps more important, by floods. Where this is clearly what has happened, *Rotalia beccarii* should be removed from consideration, and the sample involved recalculated. Undoubtedly some samples shown on the chart appear too shallow, due to the influx of this species.

As equivalent changes in depth have a much more apparent effect on the faunules of the shallower bottoms than on those of the deeper bottoms, plotting on a semi-logarithmic scale, starting the plot from the deeper side, might give a truer idea of the relative changes of water depth. This would also reduce misplaced *Rotalia beccarii* to their proper importance.

USES OF CHART

The chart should be readily adaptable to correlation within a limited area. The apparent oscillations, the relationships between the various foraminiferal

elements, and even the populations of the several elements should be useful locally.

Regionally it must be used with some care. At the Lirette and DeLarge fields wells have not drilled through the "Miocene" to the Anahuac formation. We have no base from which to count oscillations. Nevertheless, if wells are sufficiently close together, it is believed they can be correlated by this method. In the older parts of the Tertiary of the Gulf Coast the method certainly could be used.

On a chart based on cores, a sudden shift of the dominating group, for example from I to IV (Fig. 1a), without passing through intermediate stages with dominating II and III, would suggest that part of the section is missing. Group I on IV would suggest either unconformity or faulting, IV on I (Fig. 1b), faulting, or more unlikely, rapid deepening, *et cetera*. Data from several wells should permit a rationalization of alternate interpretations.

In recent years many papers have appeared, pointing out the theoretical transgression of lithologic boundaries across time lines. While this deduction is a proper one, the problem remains of where and how the time line (or plane) is to be established. Probably fossil zones are as close as we have come to the ideal, but the paleontologist is well aware of their shortcomings.

If by any method we can correlate to the extent of determining that a cycle in one column is equal to that in another column, we can establish the deepest point of deposition within the cycle in each column (Fig. 2) and by tying these points together establish a time line (Fig. 3). If enough similar points can be established in other columns we can approximate a time plane. So long as all the points lie on the same side of the hinge of movement during rise or fall of the sea floor, or seaward from the strandline during a period of eustatic adjustment, all should be well. The time plane should exhibit true structure. Variations caused by accentuated local movements might be difficult of interpretation without numerous columns.

LIMITATIONS OF MODERN DISTRIBUTION DATA

A study of Lowman's Gulf of Mexico charts reveals that while all profiles show somewhat similar changes with deepening, the breaks are not at the same depths. Some of the differences in the several charts, including generic ones, are doubtless due to contrasts in type of bottom. But, as our biologic friends have so often emphasized, other important factors are light, temperature, free oxygen, other chemical content, and organic nutrients.

Lowman's data were taken almost entirely from anchor samples, and the only factor known is depth. It is to be regretted that even in present dredging operations, depth and temperature are usually the only data recorded beyond the type of bottom. Until other factors are known we can not translate our foraminiferal data, recent or fossil, into an absolute scale of any kind. We must be content with relativity. If a particular Gulf profile were arbitrarily chosen for control in order to obtain a single line depth curve the result would still be but relative.

DEPOSITIONAL DIP SECTION OF A MARINE CYCLE (HYPOTHETICAL & SIMPLIFIED)
DOMINANT GROUP ONLY SHOWN

The recognizable TIME LINE is that formed by connecting the deepest points of deposition in the various columns.

The bands formed by the dominant groups (I to VI) afford an ecologic correlation (pseudo-correlation in the structural sense) and like lithic units transgress undetermined (indeterminable?) time lines. In a wholly marine section, the shallowest time lines, beginning and ending the cycle, might also be approximated.

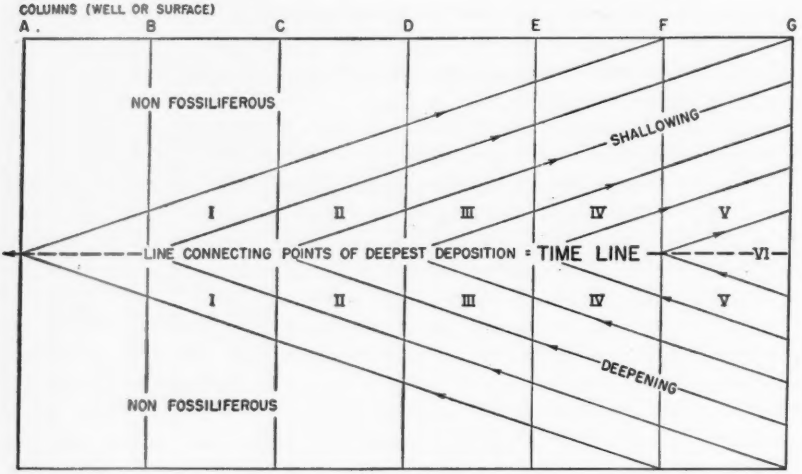


FIG. 3

FURTHER REMARKS

It will be noted on the chart that occasionally from one cutting to the next, there is a change from a large number of specimens to few or none. From similar observations in cores, the opinion is ventured that the sudden disappearance is caused by smothering, due to rapid sedimentation.

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DISCUSSION

NEW APPROACH IN STUDY OF ORIGIN OF OIL

RALPH H. FASH[1]
Fort Worth, Texas

It was with considerable interest that the writer read Ray P. Walters' article entitled, "New Approach in Study of Origin of Oil," in the September, 1948, *Bulletin*. Based on his field experience, Walters was led to the same conclusion at which the writer had arrived from theoretical considerations, namely, that the accumulation of oil as such by migration does not seem reasonable. In order to account for oil accumulation, Walters postulates the movement into the trap of oil-forming materials and not of oil itself. This idea is in accord with the theory the writer advanced in "Theory of Origin and Accumulation of Petroleum," published in the October, 1944, *Bulletin*. In that paper, it was postulated that reactive gases and liquids are formed from the decomposition of the kerogen contained in shales and limestones, and that these products, termed neokerogen, migrate in the form of films into the trap where they are converted into oil by the catalytic effect of the surfaces of the sedimentary particles.

[1] Consulting chemist. Discussion received, November 12, 1948.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

EXPLORACIONES GEOLOGICAS EN EL CENTRO DE LA REGION ORIENTAL DEL ESTADO DECOAHUILA Y EN LAS PORCIONES LIMITROFES DEL NUEVO LEON, BY FEDERICO K. G. MULLERRIED

REVIEW BY LEWIS B. KELLUM[1]
Ann Arbor, Michigan

"Exploraciones geológicas en el centro de la región oriental del Estado de Coahuila y en las porciones limítrofes del de Nuevo León," by Federico K. G. Mullerried. *Sociedad Mexicana de Geografía y Estadística*, Tomo 65, Num. 1 (1948). 118 pp., 39 pls.

This report is based on reconnaissance studies of an area of approximately 6,760 square miles (17,500 square kilometers) in the central part of Nuevo León, in northeastern Mexico. The author spent a total of six months in the area at two widely spaced periods. In 1926 he made an investigation with special reference to oil for the Instituto de Geologia de Mexico, and in 1944 he was commissioned by the University of Nuevo León to pursue further scientific studies. In the present publication he has attempted to bring together and to integrate all of the published geological data on the area, some of which he himself presented in earlier contributions.

Following the Introduction the principal part of the paper is treated under five headings: (I) Physiography and morphology, (II) History of the geological reconnaissance, (III) The rocks, strata and fossils and their geologic age, (IV) Tectonics and orogeny, (V) Geologic history, and (VI), Economic geology.

Of the four physiographic zones recognized by the author in northeastern Mexico, only two (Nos. 3 and 4) are present in the area of these investigations (from east to west): (1) the Coastal Plain, formed by horizontal sediments of Quaternary age; (2) the llanos, of Tertiary strata, somewhat inclined toward the east; (3) the zone of broken country, made up of gently folded Upper and Middle Cretaceous strata and effusive igneous rocks; and (4) the zone of mountain chains and ranges, made up of steeply folded strata of Cretaceous and Upper Jurassic age and of intrusive igneous rocks. These zones in general parallel the Gulf Coast and their mountain ranges trend northwest.

The Upper Jurassic strata are argillaceous limestones containing marine bivalves. Four localities are described in the area: (1) in the Canon de los Alamos in the southern part of Sierra Azul, alternating marls and limestones contain *Exogyra* cf. *virgula* Defrance of Kimmeridgian age identified by C. Burckhardt and included by R. W. Imlay in the Casita formation; (2) near Las Flores in the Sierra Azul, coral limestone may belong to the Upper Jurassic, but no fossil evidence is presented; (3) in the San Ambrosio well No. 1 near Camarón, northeast of Rodríguez, argillaceous and carbonaceous limestones containing Upper Portlandian ammonites identified by Imlay, were encountered; (4) in the Potrero de Oballos, a valley of the Sierra de Oballos, north of Monclova, gypsiferous strata were included by Imaly in the Upper Jurassic Casita formation.

The Lower Cretaceous strata have a thickness of 300–550 meters and consist of argil-

[1] Director, Museum of Paleontology, University of Michigan. Review received, November 11, 1948.

laceous and calcareous deposits bearing pelecypods, ammonites, brachiopods, and corals. They are present in the western part of the area in the Sierra de Santa Rosa, the Sierra de Oballos, the Sierra Azul, and possibly in the Sierra de Mercado near Monclova. In the eastern part of the area, they were identified in the San Ambrosio well No. 1 by the presence of the ammonites *Bochianites*, *Hoplites*, and *Crioceras* identified by Burckhardt. The author includes Aptian and older Cretaceous in the lower division of the period, noting that it corresponds with the Coahuila Group except for the Upper Aptian.

The Middle Cretaceous is a fossiliferous limestone series 700–1500 meters thick, with a little marl and in part containing nodules and lenses of black flint; marine pelecypods, gastropods, ammonites, and foraminifera are common. It crops out in the ranges in the western part of the area and in the Sierra de Lampazos in the southeast. Two geologic formations are represented: La Pena below, and the Cuesta del Cura above.

In the Upper Cretaceous the Turonian, Lower Senonian, and Campanian are represented by a thickness of 950–1200 meters of argillaceous and calcareous marine strata containing pelecypods, ammonites, and other fossils. The Maestrichtian is represented by 1000 feet of argillaceous-sandy deposits of marine, brackish-water, and continental origin, containing ammonites, pelecypods, gastropods, and plant remains. The Upper Cretaceous deposits are the most widespread in the area.

The Tertiary is represented by Pliocene conglomerates of the Reynosa formation, intrusions of granite, diorite, and granodiorite, and outpouring of olivine basalt. The lavas are younger than the Reynosa. They are present at the foot of Sierra de Santa Rosa along its north and east sides, and four volcanoes are present east of the town of Esperanza in the eastern part of the area.

The Quaternary consists of eolian, lacustrine river, and caliche deposits at higher elevations than the present hydrographic system. Artifacts and remains of elephants have been found in them.

The orogeny at the beginning of the Tertiary produced steep folds in the western part of the area and gentle folds in the east. The two principal directions of folding, west-northwest and north-northwest, are regarded as contemporary in origin. That the pressure increased southwest is indicated by the fact that the southwest flanks of the anticlines are narrower and steeper than the northeast flanks. Epeirogenic movements at the end of the Tertiary tilted the Pliocene conglomerates, produced faulting, and the extrusion of magma.

Under the heading "Economic Geology" the author mentions the soils, sands, gravels, building stones, ornamental rocks, surface and ground waters, non-metallic minerals, and metallic minerals.

The paper is accompanied by a comprehensive bibliography of 158 titles. The geologic reconnaissance map (Fig. 36), showing the distribution of formations, brings together the areal geology. Three geologic cross sections (Figs. 2, 37, and 38) show the author's interpretation of the regional structure. The figures are not numbered consecutively throughout the report. All three of the maps have been reduced to the point that they are scarcely legible. The thirty-two photographs showing topography, vegetation, and outcrops are all over-exposed.

The area covered by this report lies east of the "Coahuila Peninsula" of Mesozoic time, which was studied by the reviewer and his associates several years ago. Mullerried's paper brings together the scattered geological data published in a period of 60 years and interprets it in the light of his own reconnaissance observations.

THE NATURE AND ORIGIN OF LIMESTONE POROSITY BY RICHARD B. HOHLT

"The Nature and Origin of Limestone Porosity," by Richard B. Hohlt. *Quar. Colorado School Mines*, Vol. 43, No. 4 (October, 1948). 52 pp., 20 illus. Paper cover. 6×9 inches. Department of Publications, Colorado School of Mines, Golden, Colorado. Price, $1.00.

The nature and origin of porosity in limestones and dolomites have constituted a major problem of petroleum geology for many years. Such porosity may be classified as primary and secondary. Primary porosity includes all openings in a rock developed prior to and during lithification. Secondary porosity comprises those openings developed subsequent to lithification. Joints, fractures, and bedding planes control for the most part the circulation of ground waters in carbonate rocks. Greater solution porosity may be expected in areas that are structurally high than in areas that are structurally low. Given sufficient circulation of ground water, topography controls the development of solution porosity to the extent that the greatest porosity may be expected beneath areas that are topographically low. The rate of solution of carbonates is variable and is dependent upon the existent geologic and physico-chemical conditions. Selective solution causes considerable solution porosity. Some types of porosity are developed in carbonates by mineralogic changes accompanying dolomitization. It is concluded that dolomite has diverse modes of origin.

Excellent preferred orientation of grains occurs in limestones but only rarely in dolomites. Solution porosity is common to the dolomitic facies of limestones, in spite of the fact that calcite is approximately twenty times as soluble in pure water as dolomite. It is concluded that solution porosity in dolomites is a function of the random-orientation characteristics of most dolomites. It is held that ground waters can permeate more easily through randomly orientated material than through material with a high degree of preferred orientation. For this reason, dolomites may be rendered more porous than limestone by solution, irrespective of solubility.

OIL AND GAS FIELD DEVELOPMENT IN UNITED STATES 1947, BY NATIONAL OIL SCOUTS AND LANDMEN'S ASSOCIATION

REVIEW BY CLYDE G. STRACHAN[1]
Tulsa, Oklahoma

Oil and Gas Field Development in United States, Year Book 1948 (Review of 1947), Vol. XVIII. Edited by P. Wayne Ferguson and E. J. Raisch. 897 pp., maps, tables, charts (7.75×10.5 inches). Published by National Oil Scouts and Landmen's Association, Austin, Texas. Price, $8.50, cloth-bound.

This is the third time that the writer has had the privilege of reviewing these remarkable volumes on the operations of the oil industry, and the third time that he has been impressed with the impossibility of the task of reviewing such a vast array of information. The data cover every state in the Union except hard-rock-ribbed Minnesota and Wisconsin and the New England states where, for the present at least, there are no development operations.

Within this broad sweep the scout and landsman statisticians really get down to business. States are discussed individually excepting in the Rocky Mountains region and the East Coast; in the former, Colorado and Utah also get a separate as well as a joint discussion. Texas and Louisiana are divided into districts. Oklahoma may be presented as an illustration of the way the information is handled.

[1] Gulf Oil Corporation.

Under Oklahoma there is a general introductory comment on drilling, production, wildcats, and leasing. Then follow these items: (1) a pool index map; (2) a discussion of the new producing units (at West Edmond and Cement); (3) a geologic section of the state; (4) a table of the producing sands; (5) data on 1947 discoveries; (6) a list of new sands and extensions; (7) a general consideration of leasing and a table of the details of blocks taken; (8) a list of refineries and carbon black plants and data; (9) undeveloped acreage held by majors, by counties; (10) a tabulation of geophysical and core-drill prospecting by county, township, and range, with a summary; (11) data on the wildcat records of operators by section, township, and range; (12) oil and gas fields combined during the year; (13) the drilling record of individual companies, by counties; (14) combined drilling record of all companies, by counties; (15) a tabulation by years of completions from 1901 to 1947; (16) a tabulation of all fields in Oklahoma with dates, geology, and well and production data; (17) a list and data of natural-gas and cycling plants; (18) a list of production outlets for all Oklahoma fields.

The appendix forms a ready reference for statistics of the oil industry of the United States and of the world. The sources for all figures presented are cited. The index for this appendix lists 133 tabulations.

For a quick review of 1947 drilling developments the geologist will turn to the June, 1948, *Bulletin* of the A.A.P.G. Others who need a more detailed tabulation of data for the estimation of costs and trends will use the *Year Book*. Taken together they present a large part of the information which the major oil companies assemble at huge cost. Obviously, they can not include the intelligent and aggressive interpretation of the information which spells success in the oil business.

RECENT PUBLICATIONS

AFRICA

*"The Importance of Upwelling Water to Vertebrate Paleontology and Oil Geology," by Margaretha Brongersma-Sanders. *Verh. Kon. Nederlandsche Akademie van Wetenschappen, Afd. Natuurkunde*, Tweedie Sectie, Deel XLV, No. 4 (1948). 112 pp., 6 figs. 7×10.25 inches. Study based on visit to beach of Walvis Bay, Southwest Africa in 1938. In English. N. V. Noord-Hollandische Uitgevers Maatschappij, Amsterdam, Holland.

ALABAMA

*"Cretaceous of East-Central Alabama," by D. Hoye Eargle. [*Guidebook*] *Southeastern Geological Society Sixth Field Trip, November 18–19, 1948*, pp. 41–75; map in pocket. Mimeographed. 8.5×11 inches. Complete guidebook, containing geological road log, pp. 1–40, may be ordered from the Secretary, Southeastern Geological Society, Box 841, Tallahassee, Florida. Price, $3.00.

ARGENTINA

*"Apuntes sobre el Triasico y el Ordovicio de El Challao, Mendoza" (Triassic and Ordovician of El Challao), by Carlos Rusconi. *Revista Mus. Historia Natural Mendoza*, Vol. 2, No. 3 (September 30, 1948), pp. 165–98; 6 photographs. 5 figs. Belgrano 970, Mendoza, Argentina. In Spanish.

ARIZONA

Gas and Oil Possibilities of Northeast Arizona, by Dorsey Hager, Arizona State Land Department (November, 1948). 19 pp., 9 figs.

CALIFORNIA

*"Ant Hill Oil Field," by Wm. C. Bailey. *California Oil Fields*, Vol. 33, No. 2 (San Francisco, July–December, 1947 [Dec., 1948]), pp. 3–6; 3 pls.

*"Cymric Oil Field," by G. G. Pierce. *Ibid.*, pp. 7–15; 6 pls.

*"Oxnard Oil Field," by E. J. Kaplow. Ibid., pp. 16–20; 2 pls.

CANADA

*"What Leduc Means to Canada," by H. G. Cochrane. *Petrol. Engineer*, Vol. 20, No. 3 (Dallas, Texas, December, 1948), pp. 128–36; 8 figs.

COLOMBIA

**Mapa de la Republican de Colombia* (1948), Ministerio de Minas y Petroleos, Servicio Technico, Bogota, Colombia. Shows areas of exploration and exploitation by companies. In colors. Scale 1:2,000,000. 33×41 inches.

ENGLAND

"The Structure of East Yorkshire and North Lincolnshire," by H. C. Versey. *Proc. Yorkshire Geol. Soc.*, Vol. 27, Pt. 3 (September, 1948), pp. 173–91. Presidential address. West Yorkshire Printing Company, Ltd., Wakefield, England

GENERAL

**Human Geography*, by C. Langdon White and George T. Renner, 692 pp., 437 figs. 7×9.75 inches. An ecological study of human society. Appleton-Century-Crofts, Inc., 35 West 32d Street, New York (1948). Cloth. Price, $6.00.

GEORGIA

"Geology and Mineral Resources of the Paleozoic Area in Northwest Georgia," by Charles Butts and Benjamin Gildersleeve. *Georgia Geol. Survey Bull. 54* (Atlanta, 1948). 176 pp., 15 figs., 8 pls. of fossils, 2 folded maps showing geology and mines.

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COLONEL O. F. KOTICK, *chairman*, Army-Navy Petroleum Board, Room 2830 T-3, Navy Building, Washington, D. C.

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HOUSTON REGIONAL MEETING, DECEMBER 2–3, 1948

J. BRIAN EBY[1]
Houston, Texas

The Houston regional meeting of the Association was held on December 2 and 3, 1948, at the Rice Hotel, Houston, Texas. There were 1,050 registrations, making it one of the largest regional meetings yet held. In fact it was larger than the national meetings until recent years.

The meeting was devoted exclusively to the study of problems of stratigraphy, sedimentation, and tectonics of the salt-dome region of the Texas and Louisiana Gulf Coast. There were no field trips.

A breakfast was tendered to authors of all papers given at the meeting on the morning of the opening day. In addition to the Friday night dance which was semi-formal, there were a style show and luncheon for the ladies and a stag luncheon on Friday.

All of the officers and members of the executive committee of the Association were present: Paul Weaver, president; C. E. Dobbin, past-president; Roy M. Barnes, vice-president; J. V. Howell, secretary-treasurer; C. L. Moody, editor. The local arrangements were in general charge of George S. Buchanan of the Sohio Petroleum Company and A. F. Childers, president of the Houston Geological Society.

Abstracts are attached, descriptive of some of the papers presented at this meeting.

ABSTRACTS

1. Recent Sediments of Mississippi Deltaic Mass, H. N. Fisk, Humble Oil and Refining Company, Houston.

The Recent deltaic mass of the Mississippi River is a huge pile of seaward-thickening deposits which underlies the deltaic plain and continental shelf. It rests upon and buries a rugged surface sculptured during the last ice age when sea-level was 450 feet lower than at present. The sediments were deposited as the last Pleistocene ice sheets melted and sea-level rose, and their main lithologic characteristics reflect the gradual lowering of stream gradients. The mass can be divided into a substream of permeable, gravel-bearing sands and a finer-grained topstratum of relatively impermeable, more heterogeneous sands, silts, and clays. Lithologic, textural, and faunal characteristics of depositional units within the topstratum are similar to those of sediments now accumulating within depositional environments of the region.

These environments are mainly marshland and pro-delta marine, but they also include more restricted ones such as the fluviatile and brackish-water channels, bay and lake bottoms, and local beaches and spits. Interfingering and overlapping relationships of the various facies in the topstratum show that the Mississippi River changed its position many times while sea-level was rising. That active subsidence accompanies the deltaic accumulation is shown by the seaward tilt of mappable marine beds within the mass and by the slope of the late Quaternary surface underlying the Recent deposits.

2. Stratigraphy of Frio Formation. Orange and Jefferson Counties, Texas, Frank Reedy, Jr., division geologist, Crown Central Petroleum Corporation, Houston.

Recent developments in the Gulf Coast of Texas have indicated the productive possibilities of many of the sands composing the lower part of the thick Frio formation of Oligocene age. Exploration to the deeper sands of the Frio discloses facts of depositional conditions of this formation, which are as critical as structure for the accumulation of petroleum.

The area comprising northern Jefferson County and Orange County is herein considered as a stratigraphic unit. Electrical-log, strike, and dip sections have been constructed indicating the basis for the correlations, the lithologic character of each of the zones of the Frio formation, and the calculated isopach interval of each zone. Diagrammatic dip sections have been drawn showing the relationship of lithology with microfauna occurrence. To interpret accurately these correlations and apply the zonation for a structural basis, three isopach maps have been constructed. These isopach

[1] Consulting geologist.

maps indicate the extent of sands, their depositional position, and the development of the shale wedge.

In Orange and Jefferson counties the Frio (Oligocene) formation is divisible into three lithologic units: an upper unit consisting primarily of sands; a middle unit of marine shale; and a lower unit consisting of sands and shale. Isopach maps reveal the location of ancient offshore bars and re-entrant basins and also show local thinning of beds in areas of structural uplift. The variation in stratigraphic position of certain foraminiferal associations is believed to be due to ecological changes and to the marine progressive overlap.

3. Salt-Dome Configuration, Marcus A. Hanna, Gulf Oil Corporation, Houston.

Factors which cause modification of a symmetrical plug to the configuration of the various salt stocks found in the Gulf Coastal area are evaluated. This configuration includes the limestone, gypsum, and anhydrite cap rock, as well as the spines, overhangs, and leaning plugs. Considered also are certain salt-stock rim-synclinal effects, as well as some resulting structural changes in the surrounding sediments.

The character of the salt as a metamorphic rock, the orientated fabric of certain of the anhydrites, and the modifications caused by density differences in the salt and surrounding sediments, and the effect of circulating waters are cited. Several of the theories of salt-plug origin and growth are considered in light of present information.

4. Sedimentary Facies of Upper Cenozoic and Recent in Gulf Coast Geosyncline, Shephard W. Lowman, Shell Oil Company, Inc., Houston.

Production of oil in the Tertiary formations of the Texas and Louisiana Gulf Coast is distributed in elongate trends that parallel the present coast. These trends coincide with the distribution of shallow marine and brackish sedimentary facies in the producing zones. There are also three prominent crosstrends along which the majority of the production is concentrated. These coincide with the three transverse embayments that cut perpendicularly across the elongate producing trends. These crosstrends indicate the intersection of another set of sedimentary conditions which are related to the embayments.

Sedimentary facies is defined as the present aspect of the rock, including its fossil content. Fossil assemblages in the Recent characterize environments, such as brackish, continental shelf, and continental slope. These relationships seem to be readily applicable to the Tertiary, but the various methods of applying them, all require a broad empirical base of stratigraphic correlation. The network method of stratal correlation is described and the facies nature of formation and of fossil zones is discussed against the combined background of faunal control in the Recent and network of correlations in the Tertiary.

Sedimentary facies and stratigraphy in the Gulf Coast Upper Tertiary are applied to two general problems. First, the presence and probable character of the Gulf Coast geosyncline are considered; second, the stratigraphic and facies data are applied to the problem of subsidence under load.

5. Tertiary History of Gulf Coast Geosyncline, M. M. Sheets, Production Maintenance Company, Houston.

The Gulf Coast geosyncline was first described by Barton and Ritz in 1933 as a long, narrow trough-shaped depression located parallel with and just inland from the shore of the Gulf of Mexico in Jefferson County, Texas. Since that time well data have made it impossible for such a trough to be present at drillable depths under the land. Geophysical data completed within the last few years seems to eliminate the possibility of such a trough under the continental shelf. In light of the new data, the former idea of the Gulf Coast geosyncline in the form of a long, narrow trough must be changed to a new concept of a bowl-shaped depression corresponding more or less with the form of the present Gulf of Mexico. Many additional data on sedimentation and structure, particularly faulting, supports this change in views.

This change in ideas may necessitate radical revision in the Tertiary history of the Gulf Coast, and doing so may cause radical revision of ideas of the thickness and character of the Tertiary and post-Tertiary sediments near shore and under the continental shelf.

In general it now seems that the Tertiary history of the Gulf Coast involves the following fundamental principles.

1. A large semiround bowl-shaped depression at the close of the Cretaceous and remaining relatively stable through the Tertiary.

2. Sedimentary filling of this depression during the Tertiary from the sides toward the middle.
3. Subsequent minor elevation of the north and west shores perhaps due to isostatic adjustment.

6. Photogeology in Gulf Coast Exploration, Charles W. De Blieux, Louisiana Land and Exploration Company, New Orleans.

The Gulf Coast has long been noted for the absence of surface deformation and topographic expression of subsurface structure. However, with application of geomorphology as a basic principle, aerial photographic interpretative techniques have been developed for this province. The deltaic plain of the Mississippi River and adjacent coastal marsh are selected for demonstration; approach to the problem is outlined, and photogeologic criteria are described and illustrated.

7. Exploration in Gulf of Mexico with Airborne Magnetometer, Eugene Frowe, Robert H. Ray Company, Houston.

Experimental flights with the airborne magnetometer have been made over numerous structures in the Gulf Coast area to determine the correlation between magnetic profile and known geologic structures. The results of these flights are given to show this correlation and to compare the magnetic anomalies of offshore structures with inland structures. The magnetic effect of derricks and well casings is discussed.

JOINT ANNUAL MEETING, ST. LOUIS, MARCH 14–17, 1949[1]

The 34th annual meeting of the Association will be held at the Jefferson Hotel, St. Louis, Missouri, March 14–17, 1949. Concurrent meetings will be held by the Society of Economic Paleontologists and Mineralogists and the Society of Exploration Geophysicists. Hotel room reservation request forms have been mailed to all members, and these forms should be used without delay.

Technical program.—President Weaver has appointed W. B. WILSON, Gulf Oil Corporation, Tulsa, Oklahoma, to be chairman of the technical program committee for the A.A.P.G. NORMAN S. HINCHEY, Washington University, St. Louis, Missouri, is vice-chairman in charge of technical service.

Members planning to submit papers should send, ***in duplicate***, in double-spaced typewritten form, their name, company or professional connection, subject of paper, and a 200-word abstract, to chairman WILSON, by January 1, certainly not later than February 1. Papers will be selected for the program to conform with the planned subject matter acceptable for oral presentation and to conform with the time available. Papers not acceptable for oral delivery may be included in the printed program by title and abstract.

Tentatively, the A.A.P.G. program will include a half day of presidential addresses and awards; a half day of papers of common interest for the joint session; a half day of oil-field descriptions; a half day of papers on the theme of "Reefs"; a half day devoted to foreign papers; and a half day of important miscellaneous papers.

Papers for the S.E.P.M. program should be submitted to Maynard P. White, S.E.P.M. chairman, Gulf Oil Corporation, Box 30, Ardmore, Oklahoma.

A.A.P.G. TECHNICAL PROGRAM COMMITTEE

W. B. Wilson, chairman, Gulf Oil Corporation, Box 660, Tulsa, Oklahoma
Norman Hinchey, vice-chairman, Washington University, St. Louis, Missouri
Hollis D. Hedberg, New York
Harold W. Hoots, Los Angeles
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George Sawtelle, Houston
J. B. Webb, Calgary
T. E. Weirich, Bartlesville

[1] Previous announcements about this meeting have appeared in the *Bulletin* of July, pp. 1376–77, November, pp. 2166–67, and December, p. 2332.

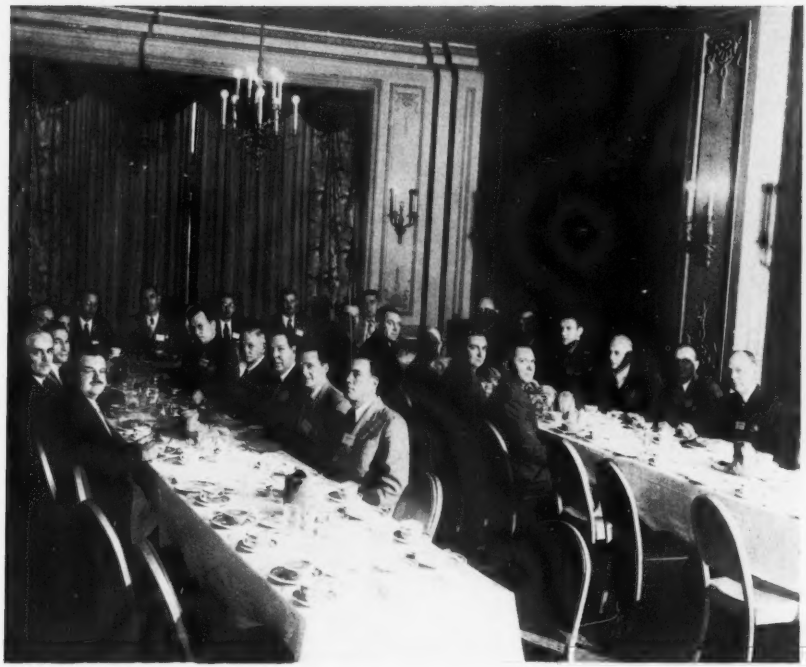


FIG. 1.—Speakers' breakfast preceding technical sessions, Houston regional meeting, French Room, Rice Hotel.

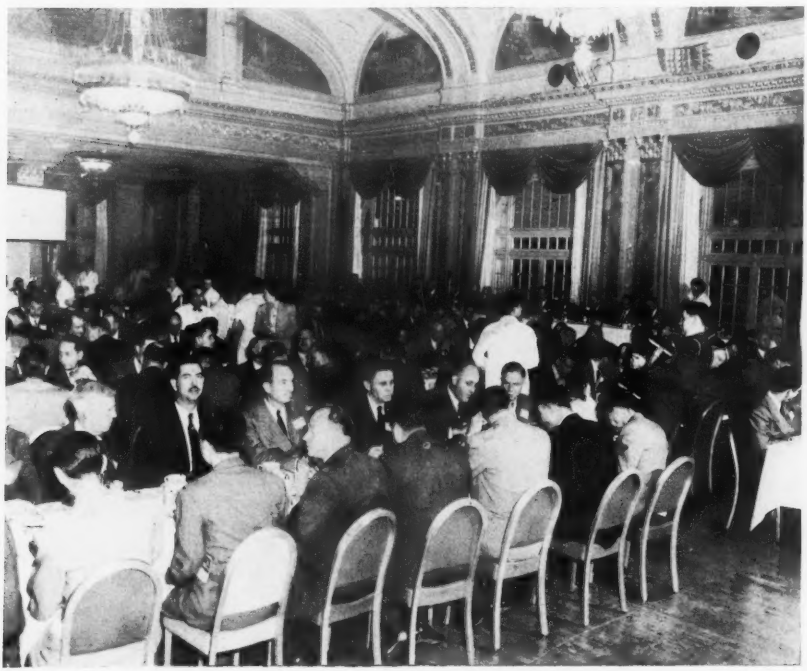


FIG. 2.—Luncheon, Crystal Ballroom, December 3.

FIG. 3.—Technical session, Crystal Ballroom.

FIG. 4.—Technical session, Crystal Ballroom.

FIG. 5.—Friday night dance, Crystal Ballroom, Rice Hotel.

FIG. 6.—At style show, Empire Room, Rice Hotel, December 3. Front row, left to right: Mrs. Don Gahagan; Mrs. W. T. Hancock, Jr.; Mrs. George Sawtelle. Back row, left to right: Mrs. Hillord Hinson and Mrs. Gene Peebles.

FIG. 7.—Houston Geological Society officials. Left to right: A. S. Gale, Jr., program equipment committee; Hillard W. Carey, technical committee; Carleton D. Speed, Jr., hotels committee; George S. Buchanan, general arrangements; R. R. Rieke, secretary; A. F. Childers, Jr., president.

FIG. 8.—Left to right: Roy M. Barnes, vice-president; C. L. Moody, editor; Paul Weaver, president; George S. Buchanan, general chairman for meeting arrangements; C. E. Dobbin, past-president.

Exhibits.—Space has been arranged on the mezzanine for the display of up-to-date methods and equipment representing the highest scientific and professional efficiency in the exploration for oil and gas.

On the 2d floor, limited space will be available to educational institutions, government bureaus, and affiliated societies for the display of *new* or *recent*, significant maps, correlation charts, aerial photographs, *et cetera*, which may be fastened to vertical panels. These displays will necessarily be restricted to vertical space in units approximately 6 feet high by 5 feet wide. Tables will not be used. Requests for space should reach the A.A.P.G., Box 979, Tulsa 1, Oklahoma, before February 1.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 1 (JANUARY, 1949), PP. 116-124, 1 FIG.

MEMORIAL

NELSON HORATIO DARTON
(1865–1948)

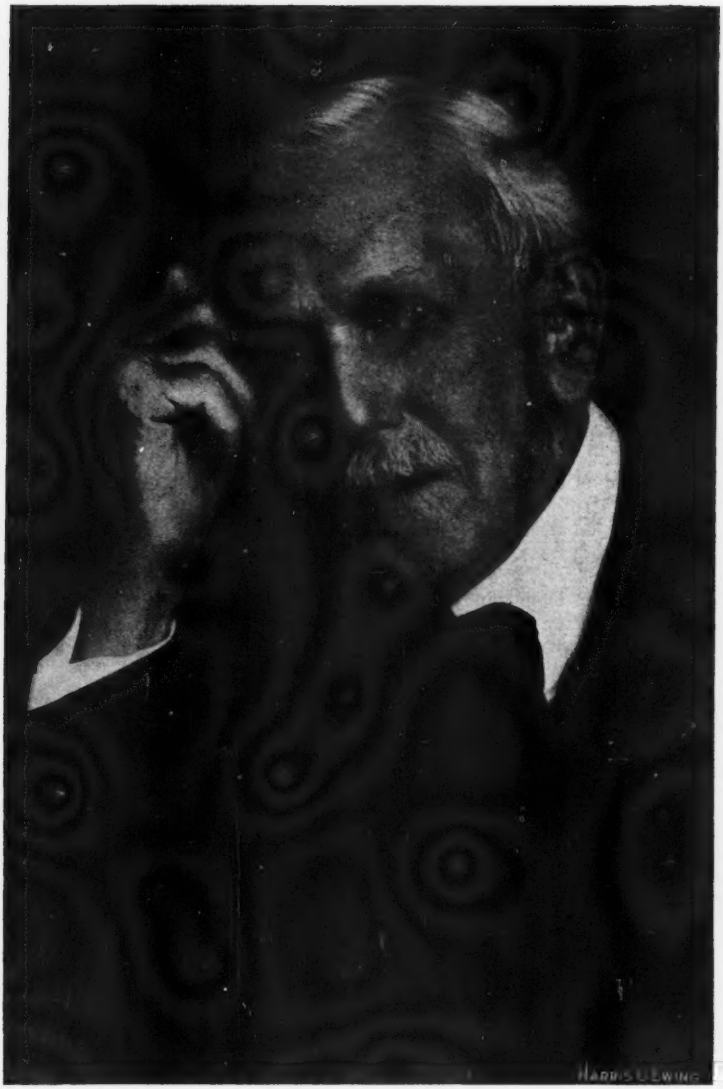
Dr. N. H. Darton, an honorary member of the American Association of Petroleum Geologists, died on February 28, 1948, in his 83d year. His active professional career, first as a chemist and then as a geologist, exceeded 65 years. It was distinguished throughout by a long series of scientific papers, lectures, and maps. His publications totalled more than 200, including 26 Geologic Folios, 7 Professional Papers, and 27 Bulletins of the United States Geological Survey. He will perhaps be best remembered for his classic reports on the geology of the Rocky Mountain and Great Plains states involving in many areas the establishment of the stratigraphic nomenclature, for starting the series of bibliographies of North American geology, for his pioneer studies in subsurface earth temperatures, for his amazing mastery of the technique of reconnaissance geology as exemplified by geologic maps of several of the western states, and for his pioneering petroleum surveys in Venezuela, Mexico, and the Dominican Republic.

Darton was born in Brooklyn, New York, on December 17, 1865. His relatively few years of formal schooling were supplemented by personal instruction in higher mathematics from his gifted father. A life-long insatiable curiosity induced him to spend much of his spare time wandering through factories, laboratories, and foundries, asking questions and acquiring a knowledge of all sorts of industrial processes.

In 1879, when he was 14, his uncle, William W. Thayer, invited him to become a chemical apprentice at a salary of $4 a week. Darton's father was in Alaska at the time and young Darton was able to persuade his mother that he should drop out of public school to obtain this more practical education. He was eager to learn all about chemical manufacturing as quickly as possible and was given practical training by his uncle, which he supplemented by theory from his uncle's chemical library. A transition in the business from manufacturing to jobbing, freed so much space in the building that Mr. Thayer allowed young Darton to equip a laboratory in the loft. Here he now spent most of his time, studying methods of analysis and the properties of chemicals in general. As he had already acquired at the age of 15 a reputation as a practical chemist, he was able to do considerable consulting analytical work, particularly on chemical problems of the tanning and sugar industries. In 1881, when he was less than 16 years old, he was elected a member of the American Chemical Society, and in that and later years he presented several scientific papers before that Society.

Darton's first interest in geology came from a small collection of minerals owned by his uncle. This led to his borrowing copies of Lyell's *Principles of Geology*, and other books such as I. C. Russell's papers on the geology of Hudson County, New Jersey. Either from this reading or from conversations he learned of the zeolite minerals in the trap rocks near Bergen Hill, New Jersey, and he collected specimens on short field trips. These trips aroused an interest in the stratigraphic and structural relations of the diabase sheets in which the minerals had formed, and eventually led to an intensive field study. In 1882 he published three papers on the occurrence of minerals in the vicinity of New York City. He also addressed the New York Academy of Sciences "On the Genesis of the Ores and Minerals of the Granular Limestone of Sussex County, N. J." Darton was now nearly 17 years old.

Always eager to explore new frontiers, Darton spent more and more time on geologic collecting trips and field studies, ranging farther afield and making friends with the leading geologists of the day. These men welcomed his enthusiasm and discussed geologic problems



NELSON HORATIO DARTON

with him. His interest was now so keen that in 1883 he began a card catalog of papers on the geology of the New York City region, which he later expanded to include all geologic articles in the Astor Library. This task took many hours of his leisure time, and the catalog soon had 4,000 entries.

G. K. Gilbert, who was in charge of work of the United States Geological Survey in the Appalachian region, needed an analytical catalog or bibliography of geologic literature of that region. In 1885, on learning of young Darton's catalog, he visited him in New York. They took a local geologic trip together, and Darton made such a good impression that Gilbert suggested he join the Survey. Darton's interest in geologic investigations was now so intense that he had little hesitation in accepting Gilbert's offer, even though it meant abandoning a profitable business in New York City.

When Darton arrived in Washington, D.C., the night of January 31, 1886, he was met at the station by Gilbert, who took him to the home of Bailey Willis, where he was to live for several months. The next morning he began work in Gilbert's office in the old United States Geological Survey building at 14th and F Streets. Gilbert, the right-hand man of Major J. W. Powell, had organized the Appalachian Division. He had three assistants, Bailey Willis, I. C. Russell, and H. R. Geiger, and had chosen Darton to be his fourth assistant. Darton now received the personal friendly guidance of such men as Powell, Gilbert, Willis, McGee, and the other "giants" of the early Survey and he advanced rapidly in his knowledge of the principles of geology.

The first task assigned him by Gilbert was completion of the analytic catalog of the geologic literature of the Appalachian region. Darton spent most of his office time from 1886 to 1889 on this project and in the end had 13,330 cards. In October 1886 Gilbert authorized Darton to prepare a similar catalog expanded to include all papers on North American geology. In April, 1887, this catalog was referred to Hague, Emmons, Irving, McGee, and others on the Survey, who recommended its completion and publication. The work on the North American bibliography was continued at intervals until 1894, when director Walcott ordered Darton to transfer the project to F. B. Weeks "on account of more important work you have on hand." Preparation of this reference series has continued ever since as a Survey function.

Although Gilbert had enlisted Darton specifically for the bibliographic work, he also recognized his exceptional aptitude for field geology. His first field assignment in the summer of 1886, the year of his appointment, was to study the Newark group of New Jersey and New York, a continuation of the field work which he had done before he joined the Survey. During his 2½ months in the field he mapped 1,632 square miles and on his return to Washington wrote a report published as United States Geological Survey *Bulletin 67*. In this bulletin Darton proved that the Watchung igneous sheets were lava flows, which was contrary to then existing opinion. This work was later expanded and elaborated into the New York and Passaic folios.

During the next several years, Darton received field assignments that seemed to have been designed to train him for his famous work in the West.

In July, 1887, Gilbert instructed him to make a reconnaissance of the region near the New and Greenbrier rivers, Virginia and West Virginia, "to ascertain the best lines for the instrumental measurement of stratigraphic and structural sections." Accordingly he examined an area of 7,500 square miles in the general area of Covington and Christiansburg, his trips being made alone on horseback.

During the following winter, plans were laid in the Survey for the new folio series. Darton was directed to map the Staunton Quadrangle, an area of nearly 1,000 square miles. The first mapping took less than 2 months, and after a little supplemental work the next year, he transmitted his map on June 1, 1889. The report was published in 1894 as *Folio 14*. This mapping and later work in the next 6 years in the belt of folded Appalachians

in Virginia, West Virginia, and Maryland developed that structural comprehension so noteworthy in his western work.

The discovery of phosphate rock in Florida and the resulting contradictory newspaper accounts of its value led Survey director Powell to send Darton to Florida in April, 1890. His training in both chemistry and geology made him particularly fitted to judge the economic value of these deposits. This trip to Florida aroused Darton's interest in Coastal Plain investigations, during which he came under the inspiring influence of W J McGee, who was in charge of the Atlantic Coastal Plain Division. At McGee's instigation, Darton was authorized to map the Fredericksburg, Nomini, and Norfolk folios, and the Coastal Plain part of the Washington folio. He also prepared maps, which are still in use, of the Baltimore and Richmond areas, and while mapping near Richmond he discovered Ordovician fossils in the slates that had hitherto been considered Archean in age.

During the course of his work on the Atlantic Coastal Plain, Darton became intensely interested in the geology of artesian wells and on his own initiative devoted much time to the study of underground waters. These studies led to the preparation of *Bulletin 138* on "Artesian Well Prospects in the Atlantic Coastal Plain"; Darton soon was recognized as the Survey's leading expert on artesian water.

In 1892 the Geological Survey's appropriation was cut so severely that many of its staff had to be furloughed or dismissed and it was plain that Darton could not continue his field work in the Atlantic Coastal Plain. Accordingly his superior, W J McGee, arranged a temporary transfer to the New York Survey to complete field work, under the direction of James Hall, for a new geologic map of the state. Compilation of this map had been commenced by McGee in 1887, but the base maps were so crude and the details of the geology of the state so poorly worked out that the results were disheartening. Darton's mapping in the field seasons of 1893 and 1894 covered 9,350 square miles, much of it being at the rate of 100–150 square miles a day—all work being done by horse and buggy and on foot! He was a firm believer in the desirability of a topographic base for adequate reconnaissance mapping; so foreshadowing his practice of later years, he prepared his own topographic base for the part of Albany County west of the Albany Quadrangle. Much of this new work was published under Darton's name in the Annual Reports of the New York State Geologist, but the new geologic map of the state, which he transmitted in 1893, was published by Hall with the name of W J McGee as author, although all the compilation and much of the field work had been done by Darton. This map with but minor changes is the current map of New York state.

Darton had now been on the Geological Survey 9 years and was considered a well rounded field geologist and an expert on ground-water problems. In 1895 Dr. Walcott, then Director, proposed that Darton investigate the underground-water problems of the West. F. H. Newell, chief of the Hydrographic Branch, wrote Darton on July 20, 1895,

> The suggestion of Director Walcott that you should be transferred to my branch struck me as particularly favorable owing to the impression I have had of your ability to do such work rapidly and economically. . . . There should be made a broad study of the subject with facts as to wells and a knowledge obtained as to geologic structure. Observation should also be made as to the use of well water for irrigation and the results on crops and soils.

Darton remained with the Hydrographic Branch until 1907, or nearly 12 years. These years were to prove probably the most productive of his life. During this period he did much pioneer work himself and also supervised the activities of a large staff of other geologists. Although the principal aims of the work were the discovery and appraisal of underground-water resources, it was wisely recognized by his superiors that these aims could only be achieved by obtaining a thorough basic knowledge of the stratigraphy and structure of the rocks involved.

Darton's first trip on this new assignment was to the artesian basin of South Dakota

and eastern North Dakota. Much of his work prior to 1900 was in the foothills of the Black Hills, because he realized that from that uplift comes much of the artesian water that flows under central and eastern South Dakota and because a thorough knowledge of the stratigraphy of those upturned rocks would aid him in predicting the occurrence of water under much of the Great Plains.

In 1900 Newell suggested a study of the geology and underground waters of the central Great Plains, to cover an area from the Arkansas River to the Black Hills and eastward from the Rocky Mountains to the outcrop of the Dakota sandstone. Thousands of well logs had to be studied, geologic classifications established, underground structure ascertained, and topographic data secured. Despite interruptions, this vast area was mapped by Darton and several capable assistants by the end of 1904, and in 1905 the results were published in United States Geological Survey *Professional Paper 32*, "Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains," a report consisting of 433 pages, 72 plates (including 3 in colors), and many geologic and hydrologic maps. Darton always considered this report, now a classic, one of his finest pieces of work.

Darton first visited New Mexico and Arizona in October, 1901, to study the underground water conditions between Albuquerque and Flagstaff. This investigation was so vital to the Santa Fe Railroad that the railroad paid his expenses and furnished him a private car to facilitate his work. On the first trip director Walcott and G. K. Gilbert met Darton at El Tovar to show him the succession of strata in the Grand Canyon. He revisited the Canyon several times in the next few years, examined it at many places, crossed the river and explored the Bright Angel vicinity with an Indian attendant, and prepared a geologic map of the Canyon. During the next two decades his publications and lectures on the magnificent scenery of the Canyon were much in demand in many parts of the Nation. Nearly 150,000 copies of his popular "Story of the Grand Canyon" have been sold by Fred Harvey, Inc., and it is still in demand.

Interest in the investigation of underground-waters developed so rapidly all over the United States that it was realized that data on well boring and special geologic studies were needed to guide the selection of sites and the drilling of deep wells. Darton was placed in charge of a newly organized Western Division of Hydrology, on January 1, 1903. Among the geologists assigned to assist Darton in the Western Division were W. C. Mendenhall, G. B. Richardson, W. T. Lee, C. A. Fisher, F. C. Calkins, I. C. Russell, and G. I. Adams. Darton continued his personal investigations on, if anything, a greater scale, but in addition he had to supervise the field work of his assistants, review their reports, and plan the extensions of their work and his own.

During the next 3 years Darton concluded work begun in 1901 in the Big Horn Mountains and the Laramie Basin in Wyoming, prepared on Congressional order a report on the Owl Creek Mountains, continued his mapping in the Black Hills, mapped a part of the Arkansas Valley in Colorado, did extensive work in several parts of New Mexico, and in 1904 did special jobs in Arizona, Nevada, and Oregon. Newspapers for years periodically revived the story of the 2,965-foot well at Edgemont, South Dakota, where in 1907 the Burlington Railroad secured a flow of a million gallons a day of water suitable for drinking and for boilers from a depth within 35 feet of the prediction Darton had made in 1905.

In 1906 the Bureau of Reclamation was organized as an outgrowth of much of the work of the Western division of the Hydrographic Branch. Newell, appointed Director of the new Bureau, was succeeded as chief of the Hydrographic Branch by M. O. Leighton, an engineer, who believed that the Branch should concentrate on the mechanics and engineering of sinking wells and should do little if any geologic work. Leighton, therefore, allowed Darton only sufficient funds to liquidate his many projects in the West, and the fine staff Darton had assembled was dispersed. Fortunately the Geologic Branch, which had supplied the funds for the geologic phases of the western underground water investigations, in later years allotted funds to Darton to salvage many of the uncompleted jobs.

Leighton's policy was not followed by his successors, as witnessed by the large amount of geologic work that has been done by the reconstituted Ground Water Division of the Water Resources Branch of the Survey. In later years Darton did several special jobs for this Division.

After the disastrous reorganization of the Hydrographic Branch, Darton was transferred on July 1, 1907, to the newly organized Technologic Branch of the Survey, whose chief was Darton's great friend, J. A. Holmes. This association continued for several years and when the Bureau of Mines was organized in 1910 with Holmes as director, Darton was transferred to that Bureau. One of his first field assignments was to collect lignite samples in the Carbon County coal field in Montana. During the 10 days he visited this area he made a geologic map of the coal field, which was published the next year as Geological Survey *Bulletin 316-c*. During these years with the Bureau he investigated structural materials that might be used in public buildings; he visited the marble quarries of White Pine, Nevada, and local sources of supply at Denver, San Francisco, Tacoma, Portland, and other parts of the country. Later work included a tour of duty with the Mine Accidents Division, studying the relation of structure to the accumulation of gas in southern Illinois and in the northern anthracite basin of Pennsylvania.

From time to time, however, he was detailed to the Geologic Branch to complete several of his unfinished western projects and to conduct special investigations. During these years he realized how much he preferred geologic to technologic work, and finally, in July, 1913, he returned permanently to the Geological Survey to devote the rest of his life to geologic and related investigations.

As soon as he returned to the Survey he was authorized to make a detailed study of the redbeds of New Mexico with special reference to the possibility of their containing commercial quantities of salt, and particularly potash. This assignment, resulting in his highly valued and comprehensive *Bulletin 794*, lasted from 1913 to 1919, but was interrupted by the need for his services in other investigations, including study of ground water and structural materials for Army camps during World War I.

In 1919, in connection with his studies of the redbeds of New Mexico, he began work on a State geologic map. He soon felt the need of more topographic maps, so concurrently with his geologic mapping, made reconnaissance topographic maps from which he later compiled the present topographic map of the state.

In 1914 director George Otis Smith proposed a series of railroad guidebooks along the principal transcontinental lines. Darton was naturally assigned the preparation of the guidebook for the Santa Fe route. He spent two months in the field studying the few parts of the line with which he was unfamiliar; his guidebook was published the next year (1915). This proved to be one report of the Geological Survey that was sold in large numbers at newsstands.

In 1916 and 1919 Darton made short commercial investigations for ground water and petroleum in Cuba and the Dominican Republic, and in 1920, when he was 55 years old, one of the major oil companies commissioned him to make a reconnaissance survey of Baja California. He left San Diego in April, and began a trek southward through this barren, almost waterless desert. From time to time he was able to return by truck or boat to San Diego, but much of the trip consisted of arduous and perilous travel through a region parts of which were almost entirely unexplored. When he arrived at the tip of the peninsula, the natives refused to believe his statement that he had come overland from San Diego for they firmly believed that such a trip was impossible. As his explorations had shown that oil possibilities were not promising, the company permitted him to publish in 1921 a general paper on the geology of the area and to prepare a map, published by the American Geographical Society, as a contribution toward the millionth-scale map of the world.

These foreign explorations had delayed starting a cooperative program which had

been arranged in 1919 between the United States Geological Survey and the Arizona Bureau of Mines, but in 1921, Darton was able to begin his field work of preparing topographic and geologic maps of Arizona. He spent 18 happy months in Arizona during 1921 and 1922, with occasional visits to the campus of the University of Arizona where he was treated as one of the faculty. In May, 1922, he felt greatly honored when the University conferred on him the degree of Doctor of Science. His new maps were completed in 1924 and were published by the State in the following year.

After additional geologic work in New Mexico and Texas, he accepted a commission from a major oil company from October, 1926, until August, 1927, to make a reconnaissance survey of the oil possibilities on the southeast side of the Venezuelan Andes. In this relatively unexplored region of poor exposures he correctly worked out the stratigraphic succession and is said to have demonstrated that the series of rocks on the southeast side of the Andes is similar to the petroliferous rocks of the Maracaibo Basin.

On his return from Venezuela, Darton resumed work begun in June, 1925, on a new geologic map of that part of Texas outside the Coastal Plain. He reviewed and checked in the field all previously published information, and petroleum companies freely gave him what information they had. He soon found, however, that much of this vast area was geologically unexplored. Fortunately adequate topographic maps were available for much of the rugged Big Bend country but in other critical parts of trans-Pecos Texas he made his own topographic maps as bases for the geology. These maps were made in his geologic notebook by plotting a running compass traverse, metered by his automobile odometer, and taking compass bearings on all topographic and cultural landmarks. Darton's amazing ability to judge relative altitudes by eye was checked from time to time by barometer readings. At the same time he sketched on these crude plats all the geology of the region, controlled wherever possible by fossil collections. These field plats were gradually built together into 30-minute sheets showing both topography and geology, using for control all triangulation stations and bench-marks. The resulting field sheets were in Darton's words meant to present a "valid rather than an accurate map" of the area. The writer was fortunate in spending 2 summers in Texas as Darton's camp-hand and driver and learning the field methods of this master of reconnaissance. He still finds it almost incredible that those field topographic and geologic maps grew at the rate of 500 square miles a week! Darton completed this major task of mapping in six field seasons.

Darton nearly always made it a practice to transmit his complete report or map as soon as possible after completion of field work, generally in the winter following the field season. He had answered so many calls for his services, however, that necessarily he had to postpone completion of some of his assignments. During the last four years before his retirement he completed many of these tasks, including preparation of a State geologic map of South Dakota, now in course of publication, and drafting of many of his reconnaissance topographic sheets of Texas, which are now available to the public in the Library of Congress map collection. He also made a detailed study of the sand and gravel resources of parts of Virginia and Maryland, incidentally obtaining much new stratigraphic and physiographic information.

When he reached the age of compulsory retirement in 1935, President Franklin D. Roosevelt granted him a year's extension. He was detailed to the Fuels Section of the Survey and prepared a report and contour map of the structure of the northern anthracite basin in Pennsylvania.

In 1936 when Darton was 71, he was retired, more than 50 years after he had joined the Survey. The chief geologist, however, knowing his tremendous productive ability, authorized his continued use of his Survey office. He made excellent use of this permission. During the next 12 years he engaged in active field work, producing a geologic map of the sedimentary formations in the Washington area, a contour map showing the configuration

of the bedrock surface in the District of Columbia, a study for the Geological Society of America of the structural relations of parts of the Coastal Plain of Maryland and Virginia, a report on some structural features of the northern anthracite coal basin of Pennsylvania, and completing several unfinished scientific papers on the geology of the southwestern states. Happily he lived to see all these published or in press. He also completed manuscript topographic maps of North and South Dakota and Nebraska, which are available for consultation. On February 11, only a few days before he died, he gave a half-hour lecture before the Geological Society of Washington on the geology of the Washington area.

After this geologic address in 1948 he complained for several days of feeling tired, and while he was asleep, during the night of February 28, his heart stopped beating. His death shocked most of his associates because few had known that Darton had suffered a severe heart attack while in Europe several years earlier.

Darton was fortunate in receiving tangible evidence of the homage of his profession during his lifetime. His colleagues recognized the tremendous areas covered in his detailed and reconnaissance mapping in the West and his pioneer work in establishing the stratigraphic nomenclature over vast areas. They also wished to honor him as the last survivor of the great exploratory geologists of American History. Besides the honorary degree of Doctor of Science from the University of Arizona bestowed in 1922, he was made an honorary member of the American Association of Petroleum Geologists in 1938; was given the Daly gold medal of the American Geographical Society in 1930; and, because of his explorations in the Southwest, particularly Baja California, his name was posted in the Society building in bronze letters in company with other famous explorers. He was granted the Penrose medal by the Geological Society of America in 1940; and he was enrolled in the Legion of Honor of the American Institute of Mining and Metallurgical Engineers in 1944. A few weeks before the end he was presented with a certificate of election as an honorary life member of the National Geographic Society. An honor that touched him very deeply was the dedication by the Kansas Geological Society of two different programs of their annual excursions for 1938 and 1940 into the Rocky Mountains—a tribute from men who were most competent to evaluate his work.

Darton was active in more than 20 American and foreign scientific and literary societies. He was the last surviving original fellow and a vice-president of the Geological Society of America, a founder and later president of the Geological Society of Washington, a charter member of the Society of Economic Geologists, a founding member of the Association of American Geographers, president for several years of the Spanish American Atheneum, and a long-time vice-president of the Alliance Française.

No memorial to N. H. Darton would be complete without mention of his wife, Alice Wasserbach Darton, who accompanied him on nearly all his field trips, sharing the hardships of camp life and easing them where she could. Only those of us who worked closely with him can appreciate the inspiration she provided. He is survived by Mrs. Darton, two sons, a daughter, and six grandchildren.

WATSON H. MONROE

Washington, D. C.
December 1, 1948

FRANK RIEBER
(1891–1948)

Frank Rieber, member of the Association, a distinguished physicist and inventor, died in New York City on June 30, 1948, of a heart ailment which had given him some concern for the past 10 years.

Activities in his chosen field were widespread but were particularly applied to electronics and sonics in which 48 patents are accredited to him in the United States Patent Office. But it was in the field of seismology that his interest specialized. In 1924 he first began to develop his refraction seismograph and later the reflection instrument. He was active from time to time in the contracting field with his own instruments. He joined the Association in 1934 and the Society of Exploration Geophysicists in 1936 and attended the annual meetings of the two societies.

While Frank was widely known among the geophysicists he also had many ardent friends and admirers among the geologists particularly in California where he maintained his office and laboratory up to the commencement of the War. During the war years he worked in New York, principally on appliances useful to the armed forces, and continued there until his death.

Frank was the son of the late Dr. Charles Henry Rieber the esteemed Dean of the College of Letters and Science at the University of California at Los Angeles and Mrs. Winifred Smith Rieber, a skilled professional artist who is well known for her portraits of famous philosophers, educators, and scientists. Thus Frank was raised in cultural and intellectual surroundings which gave him the stimulus and ambition which influenced his development. He graduated from Berkeley (California) High School and received his B.S. degree from the University of California in 1915.

Frank circulated in those groups where scientific and artistic attainments were the admission cards and he was widely known in circles far removed from those allied with geology.

Immediate relatives who survive him are his mother, Mrs. Winifred Smith Rieber; his wife, Mrs. LuGarda Mayer Rieber; two sons, William K. and Frank Rieber, Jr., and a daughter, Mrs. Rufus Ranney.

Frank was a genius and could have in all probability invented any sort of gadget needed to do any useful function. He was one of the most delightful conversational companions in the world. The more one saw of Frank the more cause to wonder and marvel at his wide scope of knowledge and his ability to analyze acutely the elements of a problem one would least suspect as stimulating any interest in his active mind. Any problem was a challenge to him. It can be said that when God made Frank he threw away the mold because there will never be another man like him. His loss will be long felt by his family and all of his acquaintances.

J. R. PEMBERTON

Los Angeles, California
November 15, 1948

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 33, NO. 1 (JANUARY, 1949), PP. 125-130, 1 FIG.

AT HOME AND ABROAD

NEWS OF THE PROFESSION

DAVID T. RICHARDS, who until November 1, 1948, was engaged in consulting work, is now employed as assistant district geologist with the Superior Oil Company in the Wichita Falls district, Texas.

JOHN GLENN MARKS is with the Creole Petroleum Corporation at Caracas, Venezuela.

JOHN C. MAY has changed his address from the Independent Exploration Company, Bakersfield, California, to the Intex Oil Company, 4801 Lemmon Avenue, Dallas, Texas.

RICHARD M. HOLLAND has left the Sinclair Prairie Oil Company to become geologist with the J. S. Abercrombie Company at Houston, Texas.

MAX W. BALL, during the past 2 years director of the oil and gas division of the United States Department of the Interior, resigned effective December 1, 1948. He plans to return to private consulting practice with offices in Washington, D. C.

HOWARD A. MEYERHOFF, professor of geology and geography in Smith College, Northampton, Massachusetts, has been elected administrative secretary of the American Association for the Advancement of Science, for a term of 4 years beginning January 15, 1949. He succeeds F. R. MOULTON.

CHARLES E. PITTMAN, formerly with the Amerada Petroleum Corporation at Duncan, Oklahoma, and Midland, Texas, has resigned to take a position as geologist with the Champlin Refining Company, Enid, Oklahoma.

J. M. HARRISON, of the Geologic Survey of Canada, spoke on "The Structural Geology in the Canadian Shield as Revealed by Air Photographs," before the Tulsa Geological Society, at the University of Tulsa, December 6. At the luncheon meeting of the Society, December 3, HUBERT E. BALE, geologist of Oklahoma City, spoke on "Evaluation of Oil and Gas Land."

ALBERT GREGERSEN, of Copenhagen, spoke at the Pacific Section luncheon at Los Angeles, California, December 9, on "Reminiscences of a Danish Explorer," outlining some of his experiences in Denmark where he has been for the past 3 years, with the Danish-American Prospecting Company.

WILLIAM S. HOFFMEISTER, research geologist for the Carter Oil Company, gave a talk before the geological seminar at the University of Massachusetts, entitled "Petroleum Geology," on the evening of November 9, at Amherst, Massachusetts.

The department of geology and geography of the University of Tennessee is sponsoring a symposium on the mineral resources of the Southeast. Sessions will be held on the campus at Knoxville, on March 3, 4, and 5. Papers on the major metallic and non-metallic mineral products of the Southeast will be presented by invited speakers.

ODELL C. OLSON has resigned as district engineer of the oil and gas division of the Railroad Commission of Texas, and is now employed at Breckenridge, Texas, in the capacity of production engineer with Fred M. Manning, Inc., drilling contractor of Denver, Colorado.

The presidential address of retiring president W. W. RUBEY of the Geological Society of Washington was given on December 8 at the Cosmos Club in Washington, D. C. It was entitled "The Problem of Changes in Composition of Seawater and Atmosphere during the Geologic Past." New officers elected at this meeting to serve for 1948 are: president, JAMES STEELE WILLIAMS of the Geological Survey; vice-president, EARL INGERSON and E. T. MCKNIGHT; secretary, R. E. VAN ALSTYNE; treasurer, Mrs. CHARLOTTE MARSH WARSHAW. Members-at-large of the council are: D. H. DUNKLE, WENONAH ECKSTEIN, P. I. KILLEEN, O. F. TUTTLE, and FRANK WHITMORE. Representative to the Washington Academy of Science is J. B. REESIDE, JR.

The Southeastern Geological Society of Tallahassee, Florida, conducted its 6th field trip last November, on which its guidebook on "The Cretaceous of East-Central Alabama" was used. The trip was led by D. HOYE EARGLE of the United States Geological Survey, Tuscaloosa, Alabama, who has recently been working on the Cretaceous in Alabama. Members of the field-trip committee from the society were: H. G. WALTER, chairman, Ohio Oil Company; J. L. CALVER, acting chairman, Florida Geological Survey; W. C. BLACKBURN, Humble Oil and Refining Company; W. B. JONES, State geologist of Alabama. The officers of the society are: PAUL L. APPLIN, president; E. H. RAINWATER, vice-president; and ELEANOR T. CALDWELL, secretary-treasurer. Guidebooks are available and may be purchased at $3.00 each by writing: Secretary, Southeastern Geological Society, Box 841, Tallahassee, Florida.

THOMAS L. ALLEN, Petty Geophysical Engineering Company, spoke on "Problems in Geophysical Exploration in South Texas and Specific Study of Washburn Field, La Salle County," at the meeting of the South Texas Section of the Association, at San Antonio, Texas, December 16.

E. P. NEAL, Tide Water Associated Oil Company, spoke on "The Geology of the Ceres Pool, Noble County, Oklahoma," at the luncheon meeting of the Tulsa Geological Society, December 17.

JOHN G. BARTRAM, Stanolind Oil and Gas Company, discussed "Oil in the Ellenburger and Arbuckle of the Mid-Continent," at the meeting of the Tulsa Geological Society, December 20.

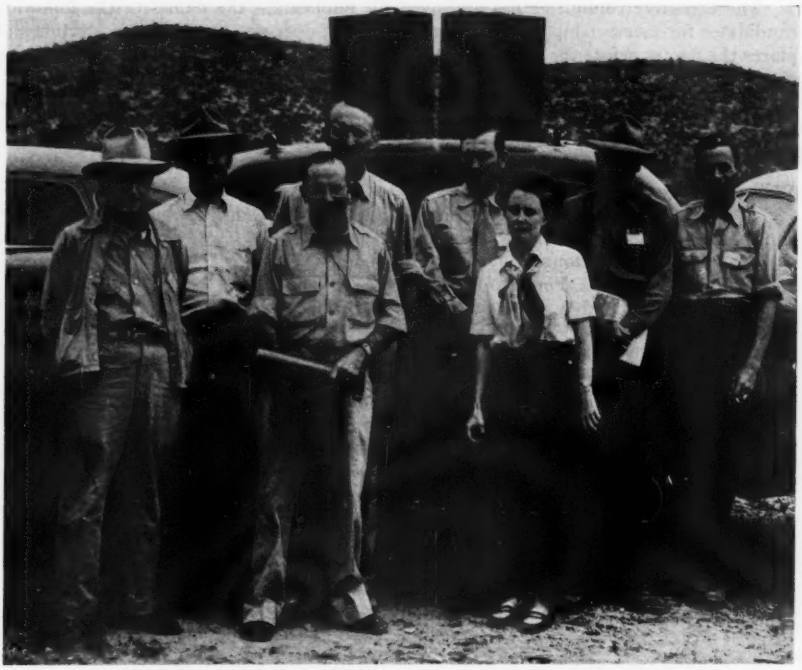
The library of the late GAYLE SCOTT, formerly editor of the A.A.P.G. and secretary-treasurer and president of the Society of Economic Paleontologists and Mineralogists, has been donated to the Texas Christian University, where he taught geology from 1919 to 1948. Each volume will bear a special gift plate, for which the art work was designed by a former student, C. IVAN ALEXANDER.

LE MOYNE W. MYERS has changed company affiliation from the Creole Petroleum Corporation, Maracaibo, to the Socony-Vacuum Oil Company of Venezuela, at Caracas.

M. GUY EDWARDS has completed 25 years of service with the Shell Oil Company. His address is 2154 N. Villa Heights Road, Pasadena, California.

The Geological Forum of the Pacific Section of the Association presented the following program of papers at Los Angeles, December 20: "The Principal Structural and Geologic Features of the Santa Maria Basin," by W. R. CABEEN, consultant geologist; "The Generalized Lithology and Stratigraphy of the Santa Maria Basin," by ADEN W. HUGHES, paleontologist and geologist of the Union Oil Company; and "Production Problems of the Santa Maria Basin Oil Fields," by AL HILTON, of the Union Oil Company.

WEST TEXAS GEOLOGICAL SOCIETY FIELD TRIP



OFFICERS OF WEST TEXAS GEOLOGICAL SOCIETY and field trip leaders on Society's Fall Field Trip, Green Valley, Solitario, and Barrilla mountains, October 29–31, 1948. Left to right: W. A. Waldschmidt, president; Clyde W. Turner, secretary; Samuel S. Goldich, University of Minnesota, leader; Ronald K. DeFord, University of Texas, leader; G. K. Eifler, Jr., University of Texas, leader; Miss Jane Marie Johnson, treasurer; John T. Lonsdale, director, Bureau of Economic Geology, University of Texas, leader; Clay L. Seward, University of Texas, leader.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Source Data

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By

J. V. HOWELL AND A. I. LEVORSEN

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- D. Miscellaneous books and publications of general geological interest
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Originally published as Part II of the August, 1946, Bulletin

PRICE, 75¢ POSTPAID

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410 Boston Building

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Vice-President - - - - - - - T. G. Wright
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - Victor F. Reiserer
Superior Oil Company, 510 K.F.H. Bldg.

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

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Vice-President and Program Chairman - - - - - - - - - - - - - - - M. N. Broughton
The Texas Company, 1500 Canal Building
Secretary-Treasurer - - - - - H. A. Nystrom
Schlumberger Well Surveying Corporation
452 Canal Building

Meets the first Monday of every month, October-May, inclusive, 12 noon, St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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427 Ricou-Brewster Building
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Secretary-Treasurer - - - - - - - - R. T. Wade
Schlumberger Well Surveying Corporation
Box 92

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Gulf Oil Corporation

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Program Chairman - - - - - - - - Gus Sanger
Pure Oil Company
Clare

Meetings: Monthly, November through May at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M. Papers follow dinner. Visitors welcome.

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Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., The Creole Room, LeFleur's Restaurant, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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The California Company, Box 153
Secretary-Treasurer - - - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

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918 Hales Building
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Phillips Petroleum Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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The Texas Company
Box 1007, Shawnee
Secretary-Treasurer - - - - - Marcelle Mousley
Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

OKLAHOMA

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Consultant, Box 2204
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Secretary-Treasurer - - - - - - - Noel Evans
Consultant, 1510 Philtower Building
Editor - - - - - - - - - - John C. Maher
U. S. Geological Survey
Federal Building

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Lorton Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

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Box 2038
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Equitable Gas Company
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Treasurer - - - - - - - - Sidney S. Galpin
Peoples Natural Gas Company
545 William Penn Place

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TEXAS

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Vice-President - - - - - - - - J. R. Day
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Secretary-Treasurer - - - - Riley G. Maxwell
Consulting Geologist
Box 1939

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

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Pure Oil Company
Secretary-Treasurer - - - - - James D. Burke
Seaboard Oil Company of Delaware, Box 601

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

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The Atlantic Refining Company
P.O. Box 2819
Secretary-Treasurer - - - - Gilbert P. Moore
Consulting, 501 Continental Building
Executive Committee - - - - - Edgar Kraus
Atlantic Refining Company
Box 2819

Meetings: Monthly luncheons and night meetings by announcement.

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Box 780
Secretary-Treasurer - - - - - - G. C. Clark
Stanolind Oil and Gas Company
Box 660

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

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FORT WORTH, TEXAS

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Box 1720
Vice-President - - - - - - - F. H. Schouten
Stanolind Oil and Gas Company
Box 1410
Secretary-Treasurer - - - - Millicent A. Renfro
Texas Pacific Coal and Oil Company, Box 2100

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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HOUSTON, TEXAS

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Consultant, 935 Esperson Building
Secretary - - - - - - - - - R. R. Rieke
Schlumberger Well Surveying Corporation
Treasurer - - - - - - - - Mary L. Holland
Stanolind Oil and Gas Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

TEXAS

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Independent Geologist, 907 Staley Building

Vice-President - - - - - Joseph W. McDonald
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Secretary-Treasurer - - - - Ralph H. McKinley
Panhandle Producing and Refining Company, Box 1191

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

SOUTH TEXAS SECTION AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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1610 Milam Building

Vice-President - - - - - - - Paul B. Hinyard
Shell Oil Company
2000 Alamo National Building

Secretary-Treasurer - - - - Maurice E. Forney
Atlantic Refining Company
1728 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

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Phillips Petroleum Company, Box 1761

Vice-President - - - - - - Robert F. Herron
Oil Development Company, 900 Polk St.

Secretary-Treasurer - - - - - Robert B. Totten
Sun Oil Company, Box 46

Meetings: Luncheon 1st and 3rd Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

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Secretary - - - - - - - - Clyde W. Turner
Republic Natural Gas Company, Box 1644

Treasurer - - - - - - - - - Jane M. Johnson
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Meetings will be announced.

WEST VIRGINIA

APPALACHIAN GEOLOGICAL SOCIETY
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Thomas Circle Road, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July and August, at 6:30 P.M., Daniel Boone Hotel.

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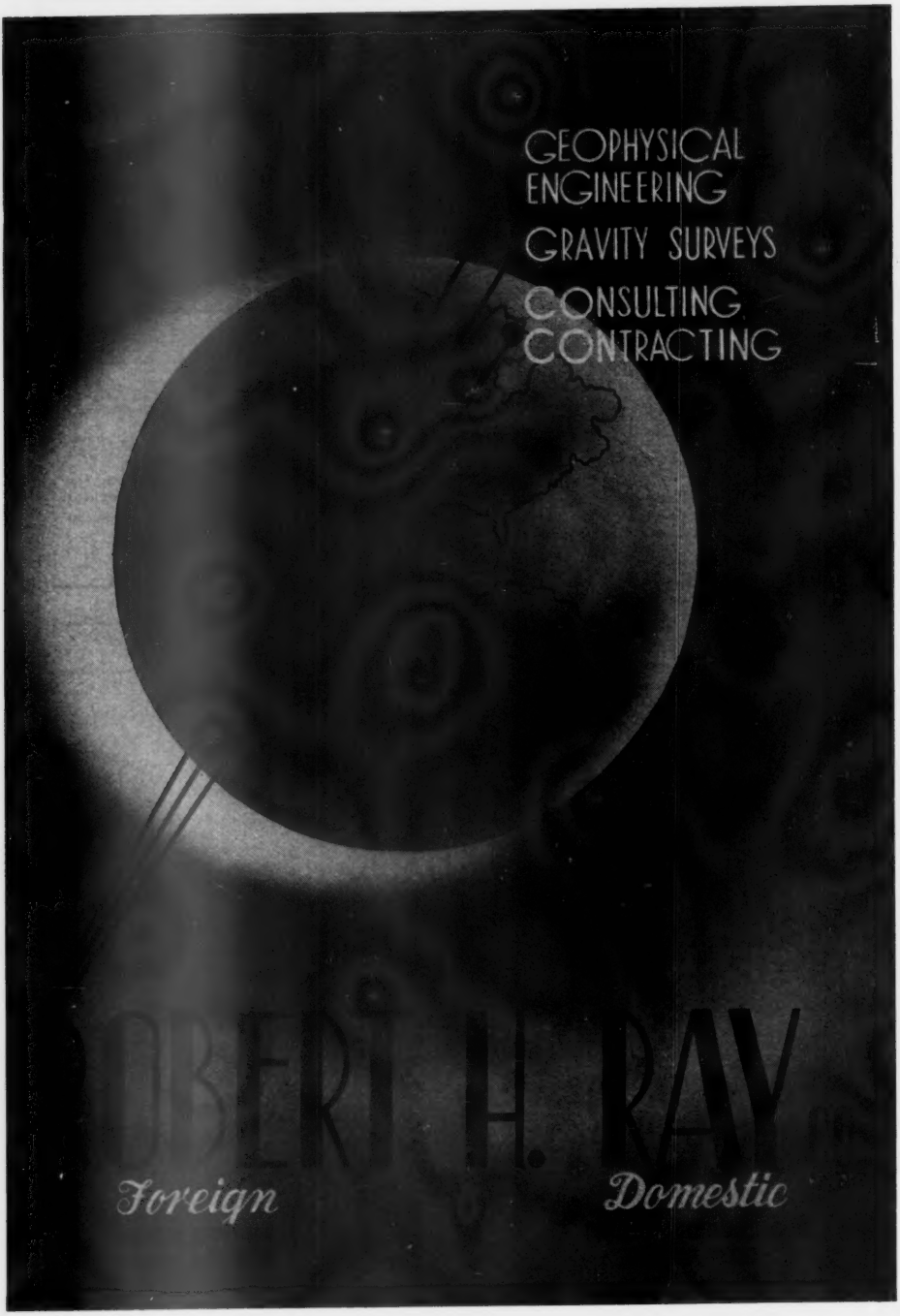
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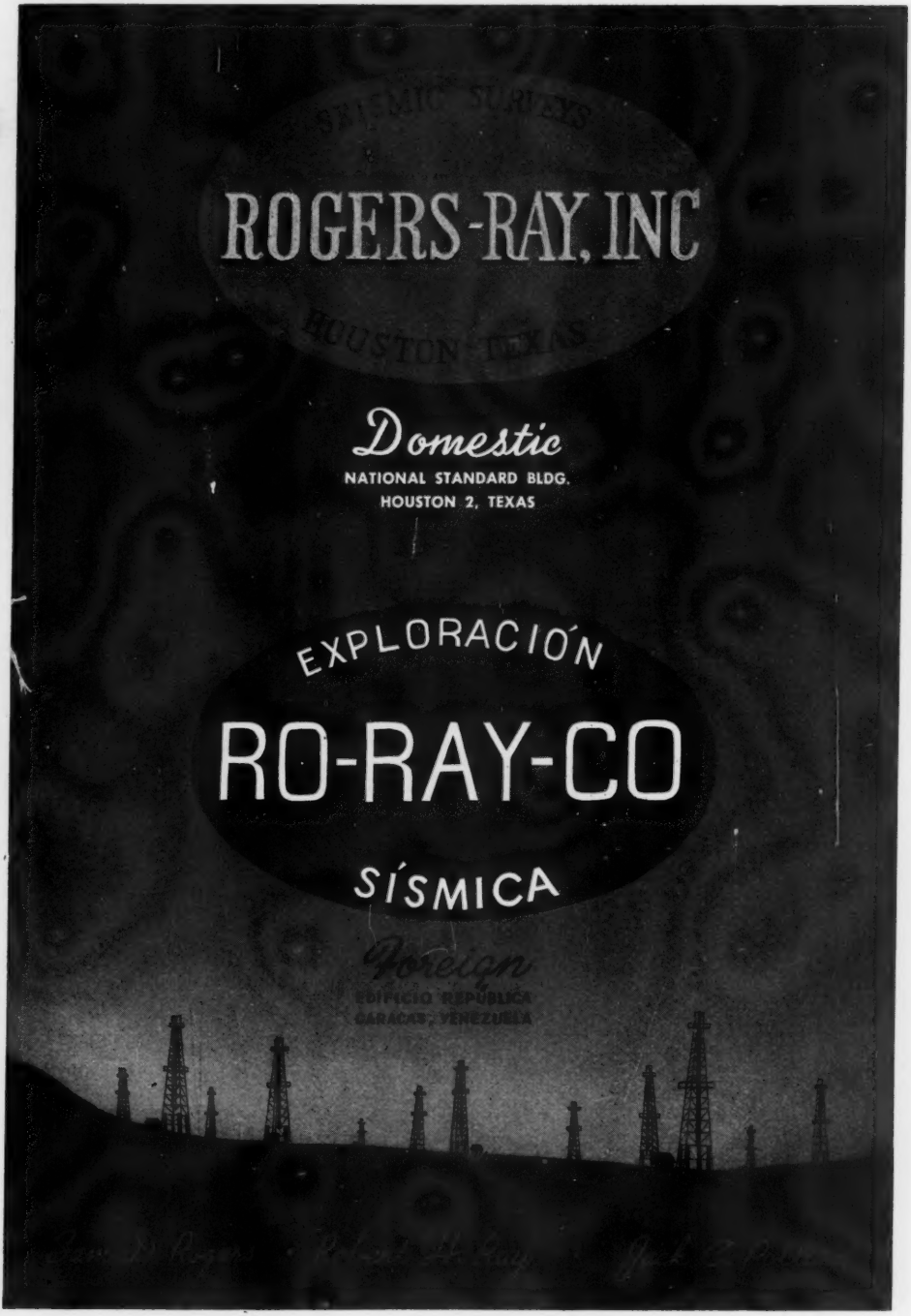
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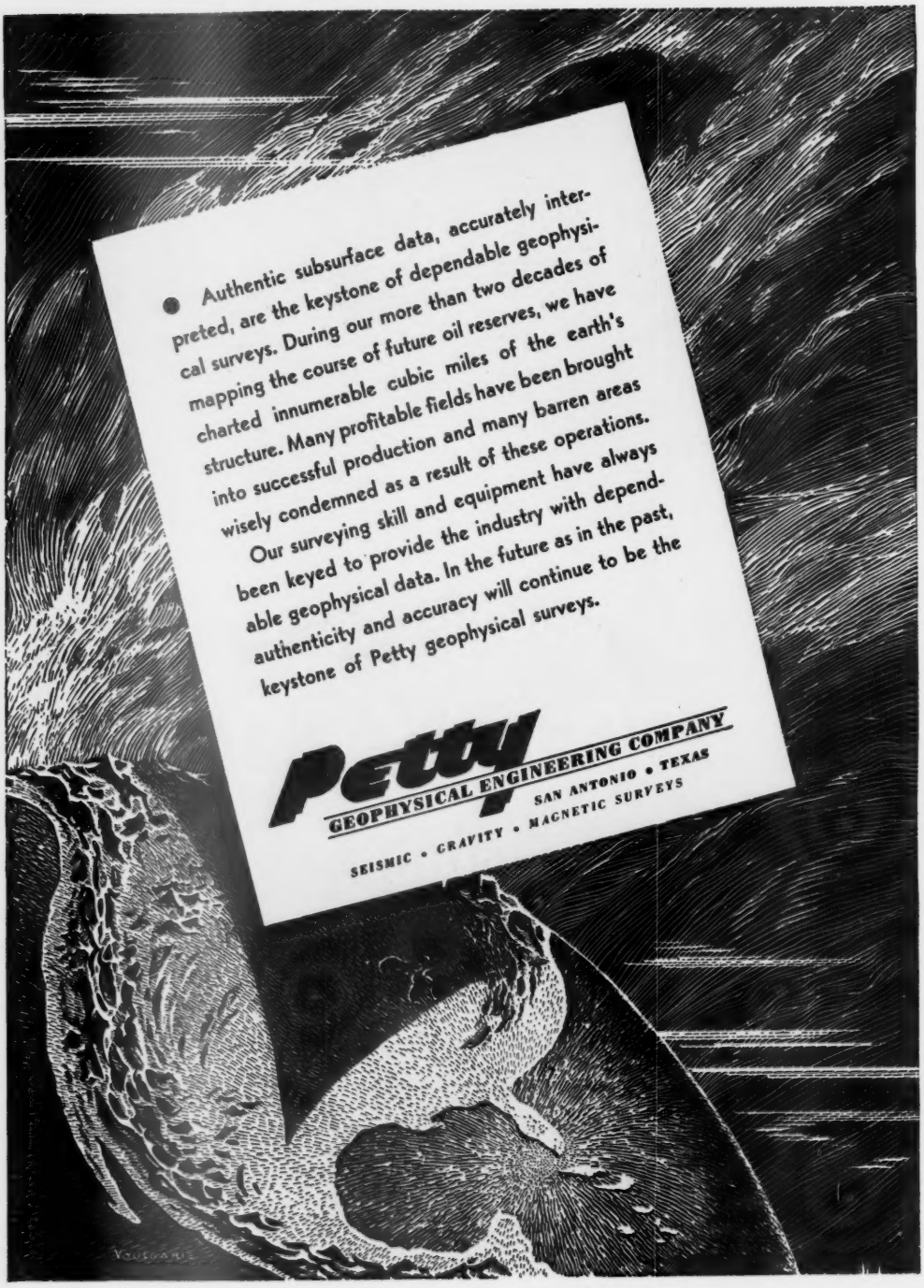
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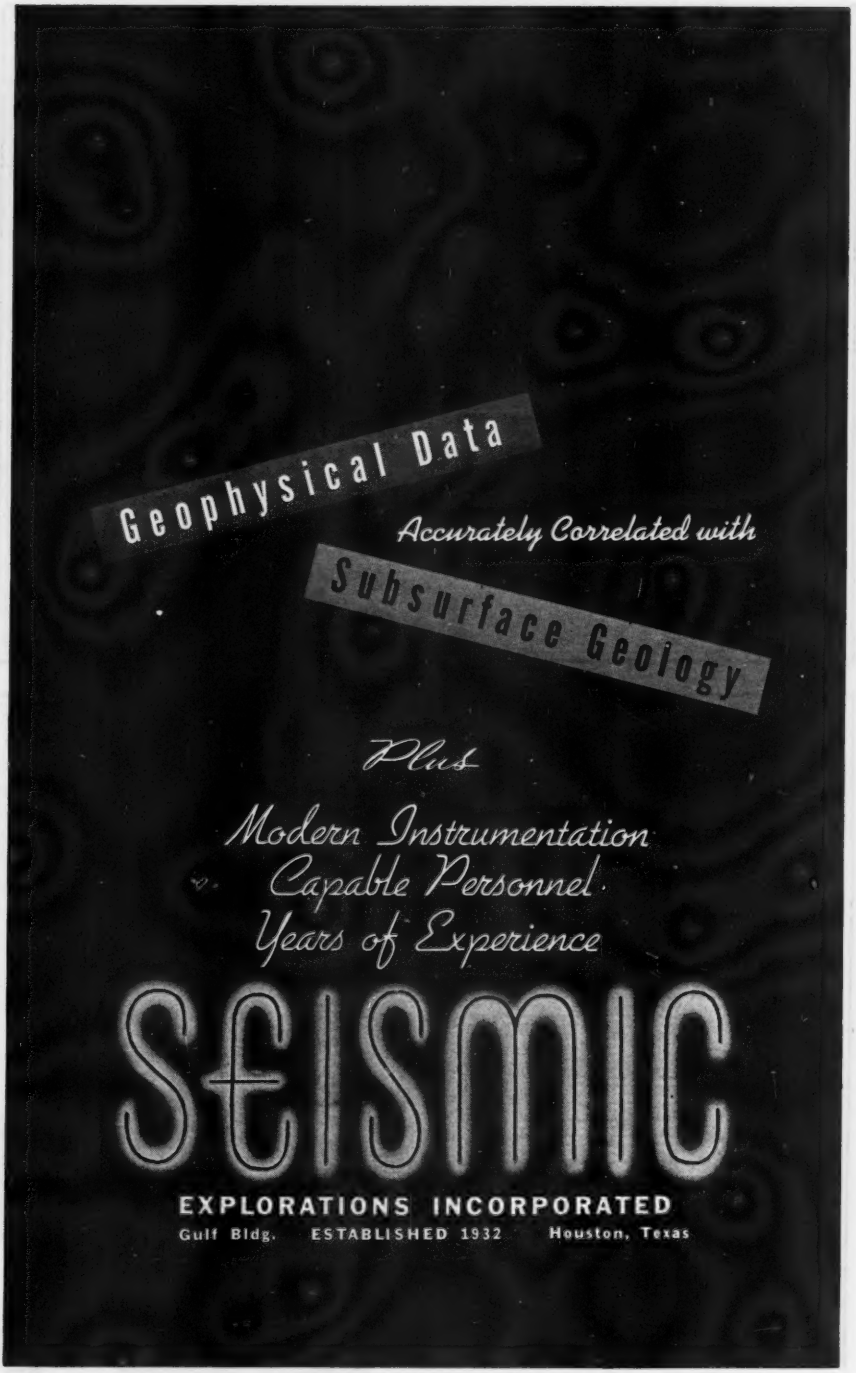
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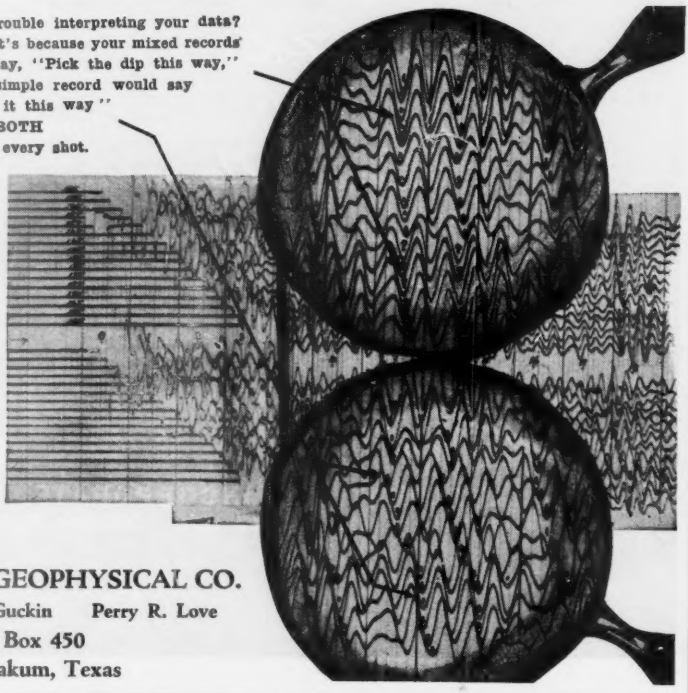

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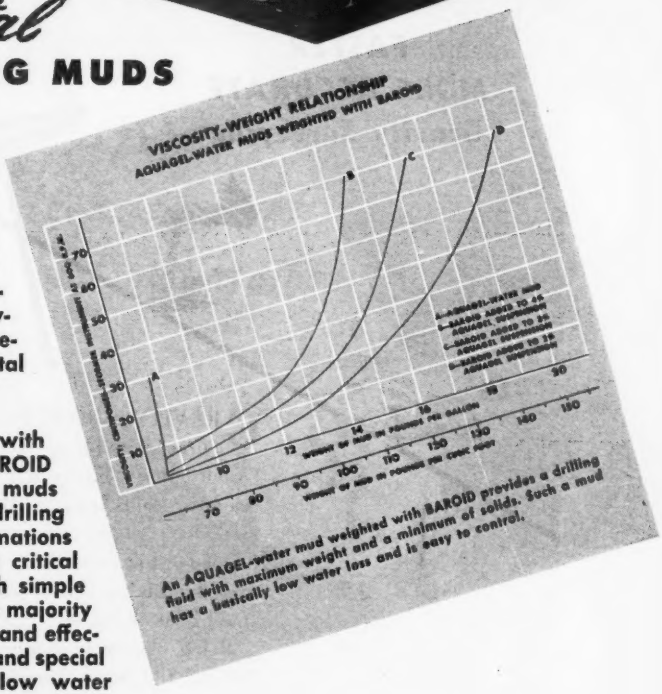

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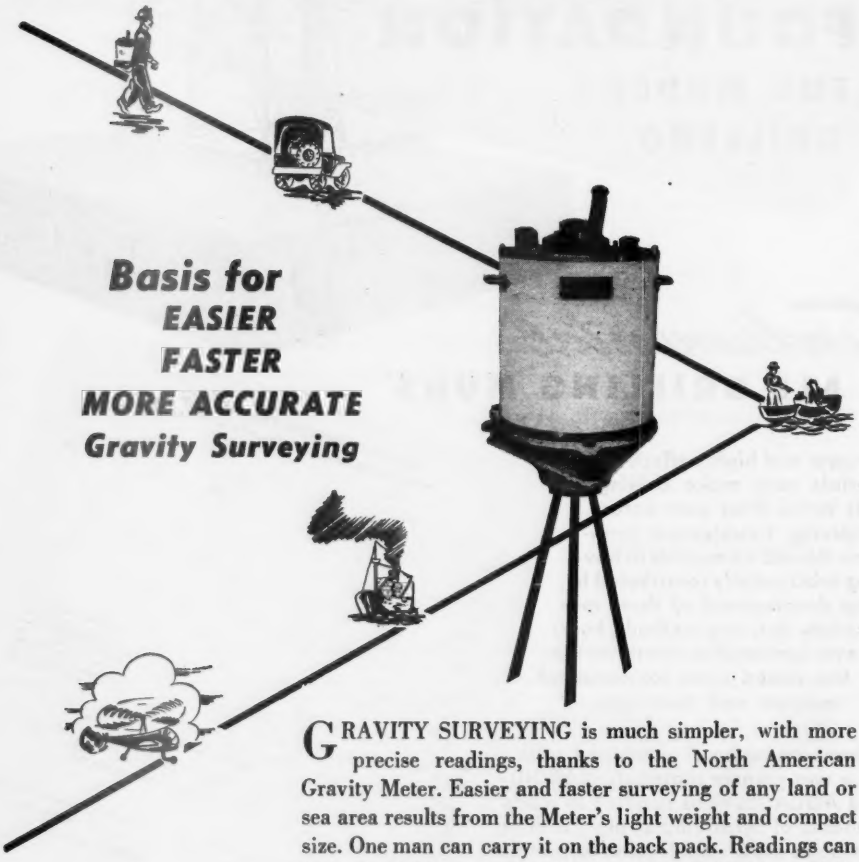

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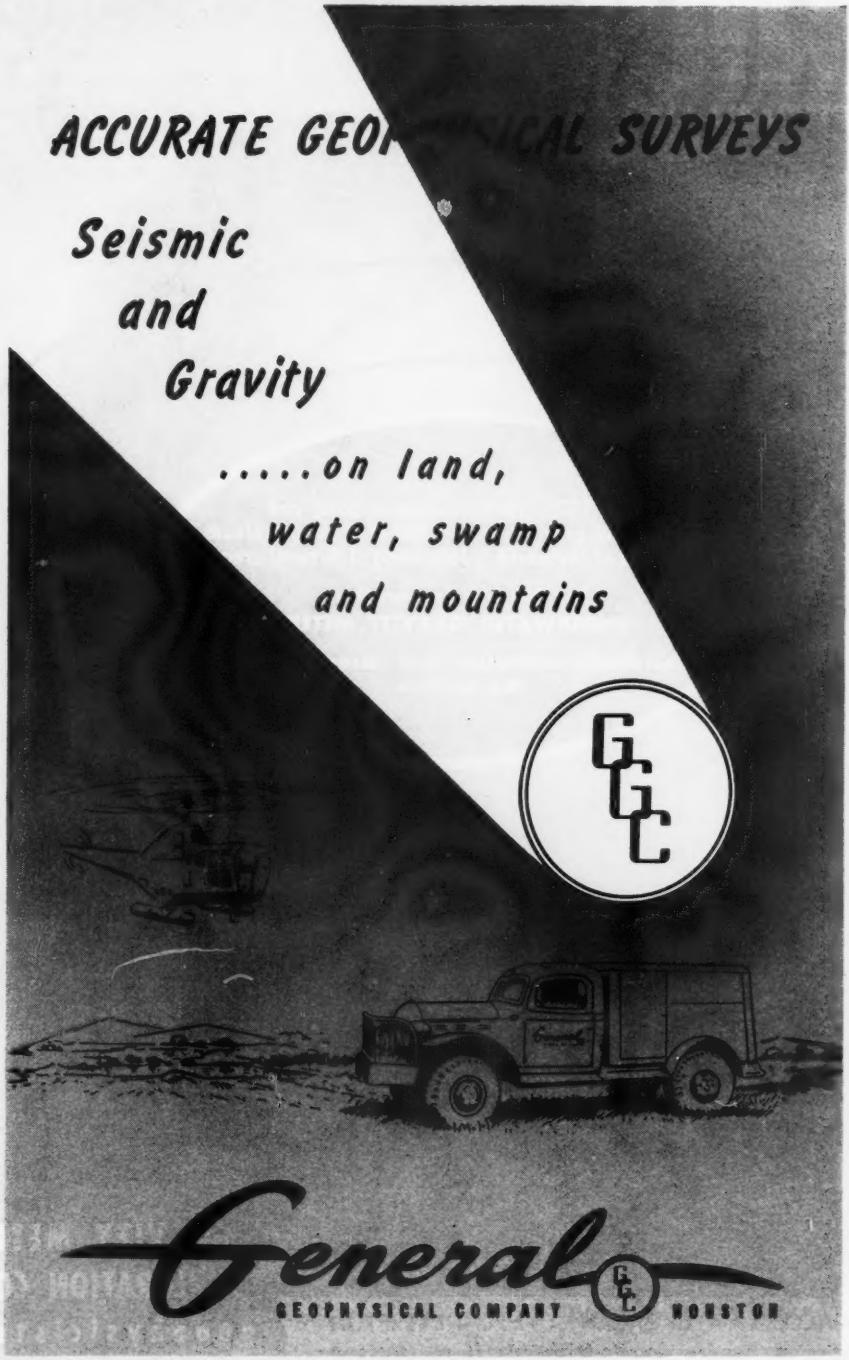
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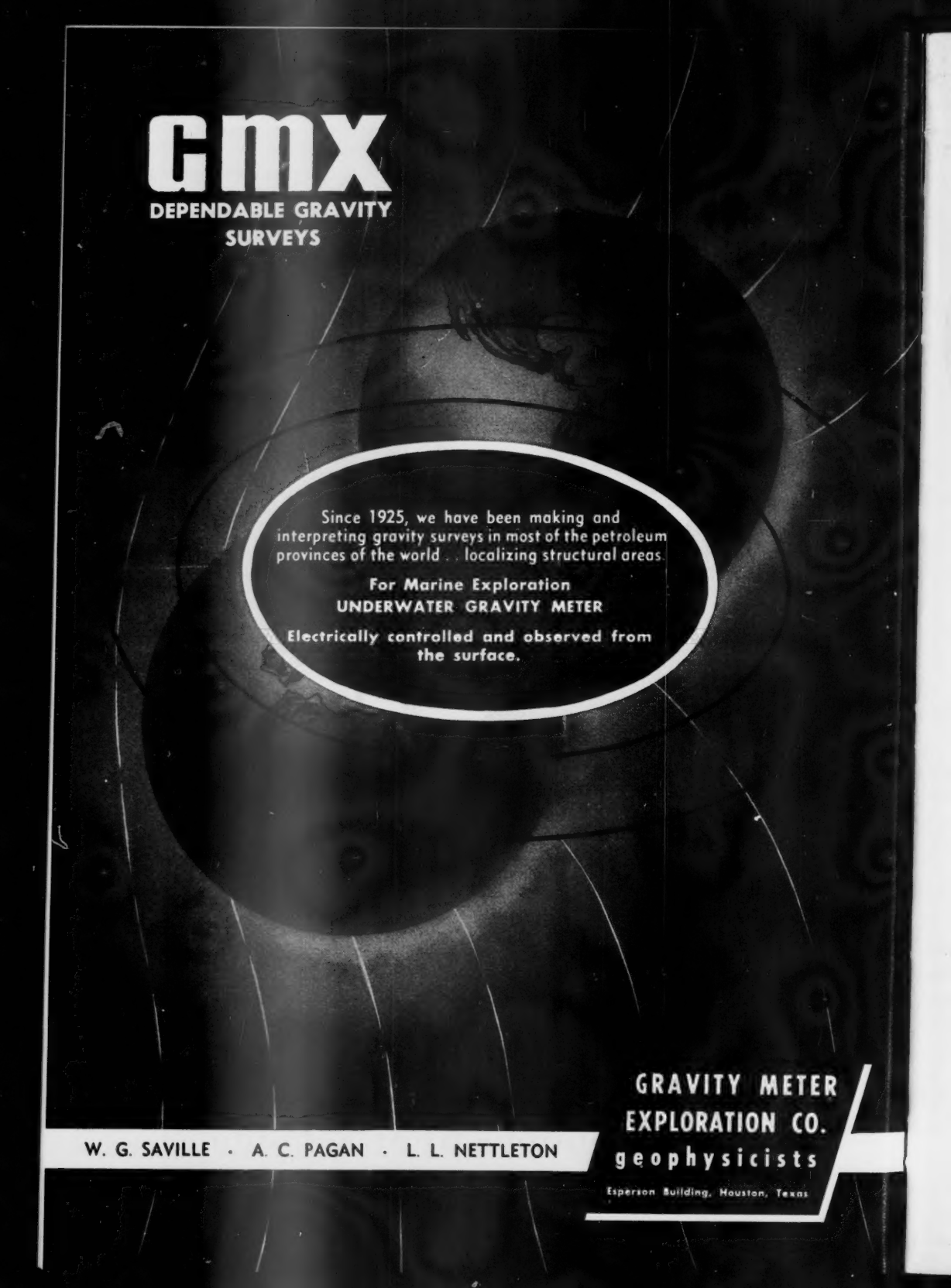

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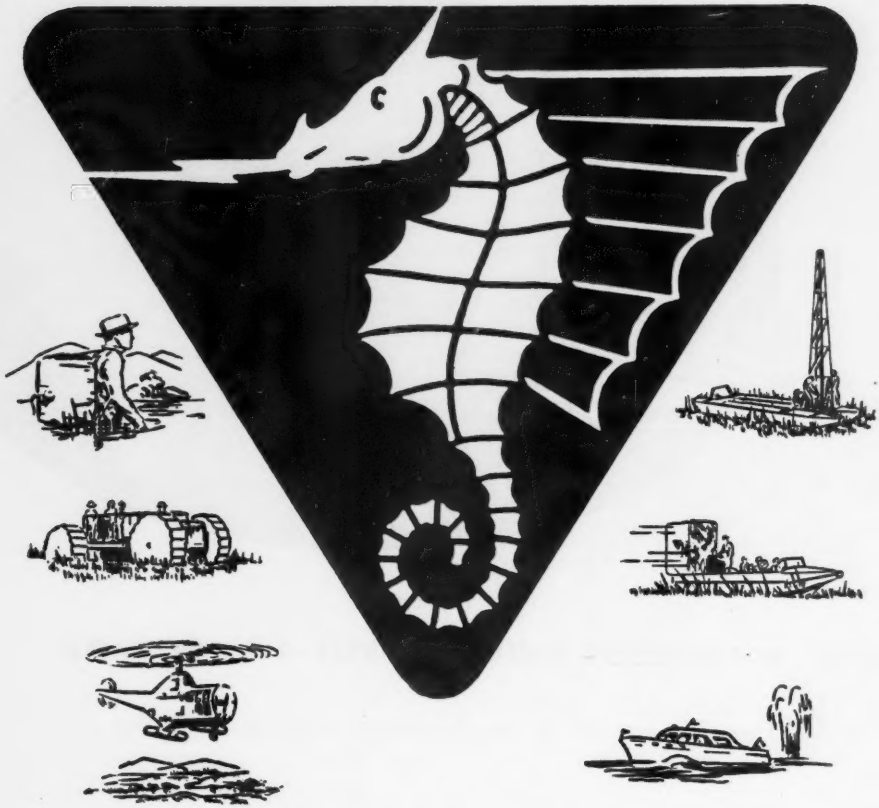

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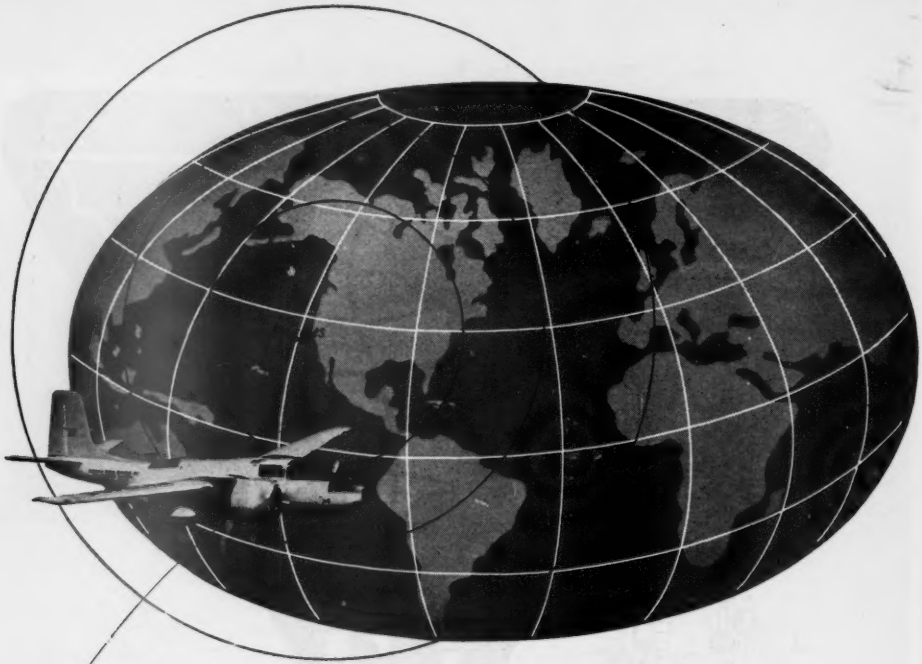

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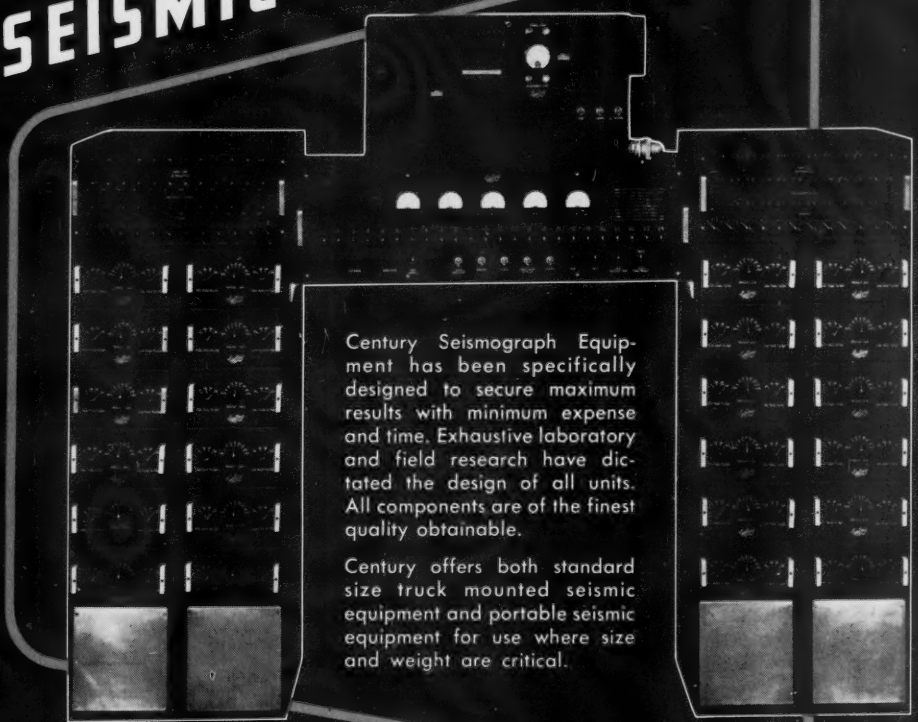

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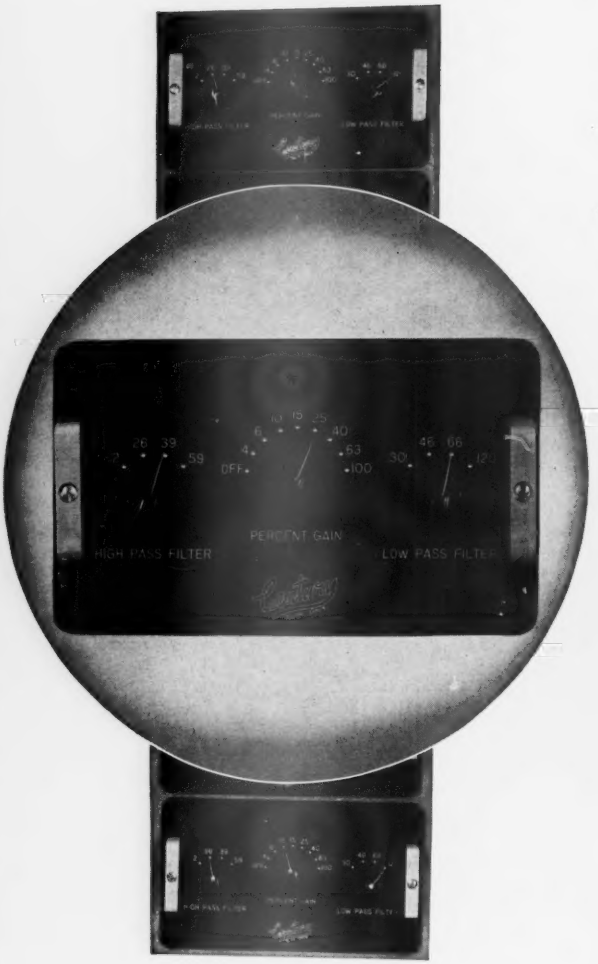

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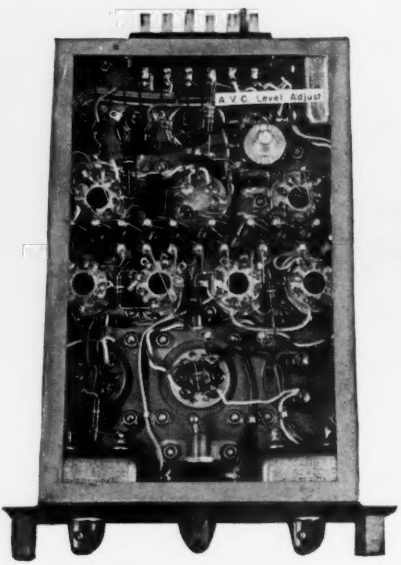

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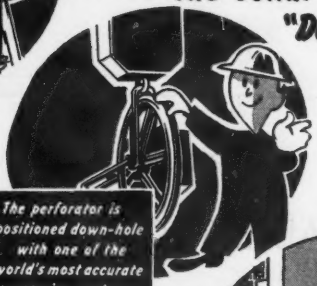

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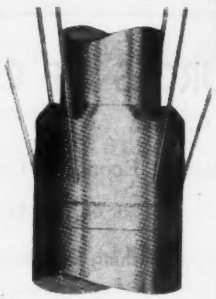

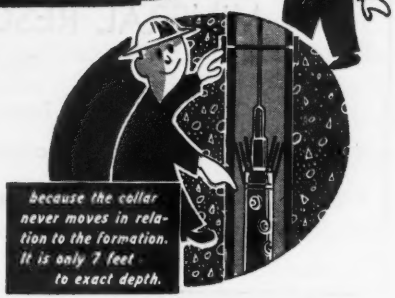

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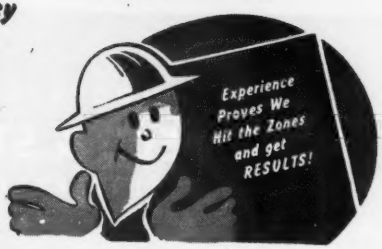

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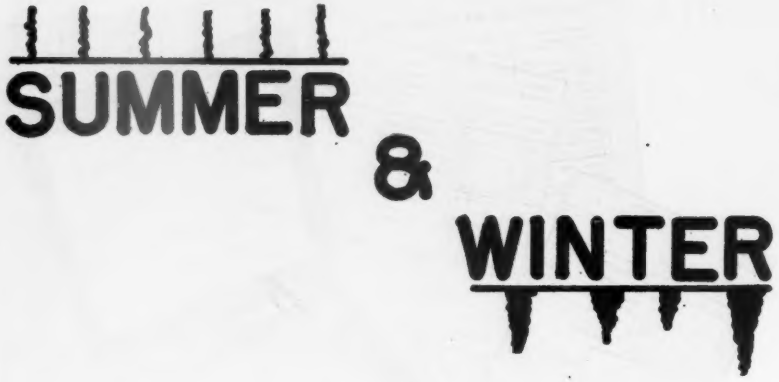

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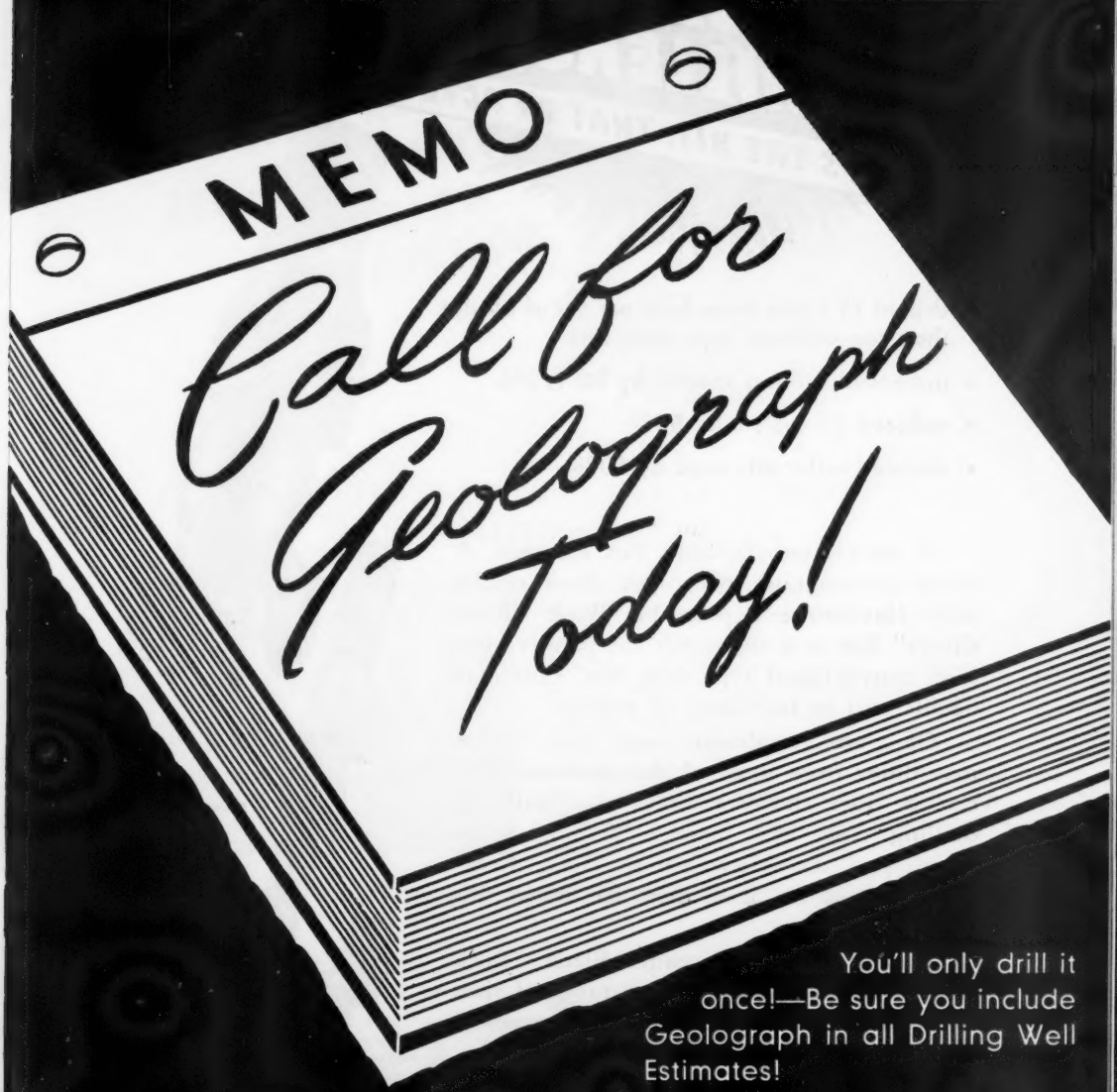

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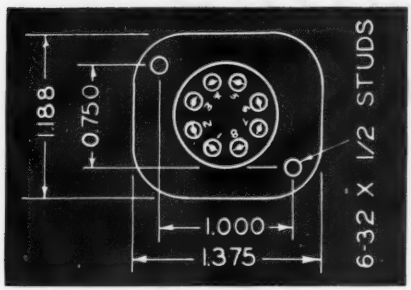

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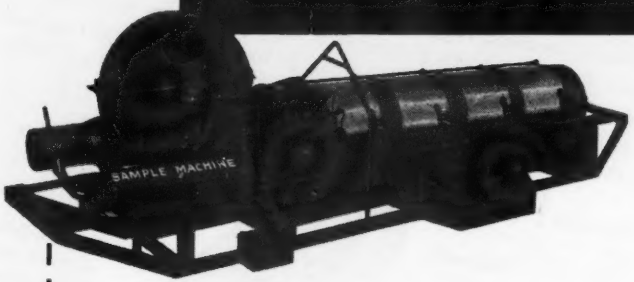

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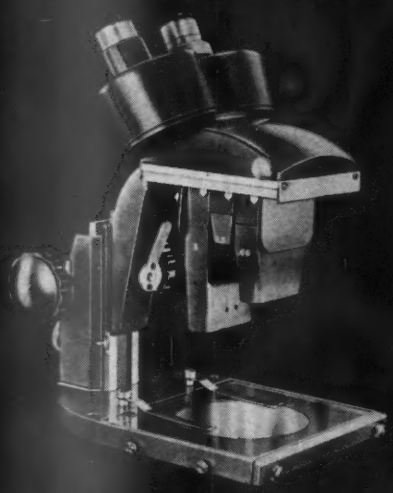

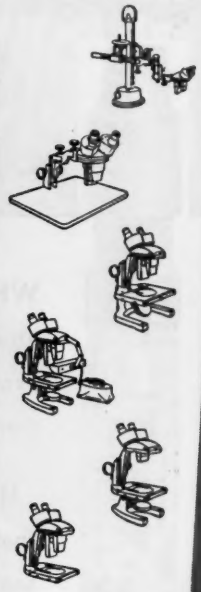

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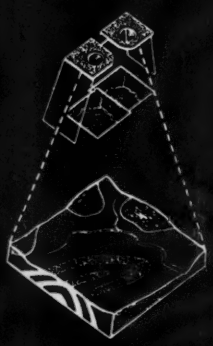

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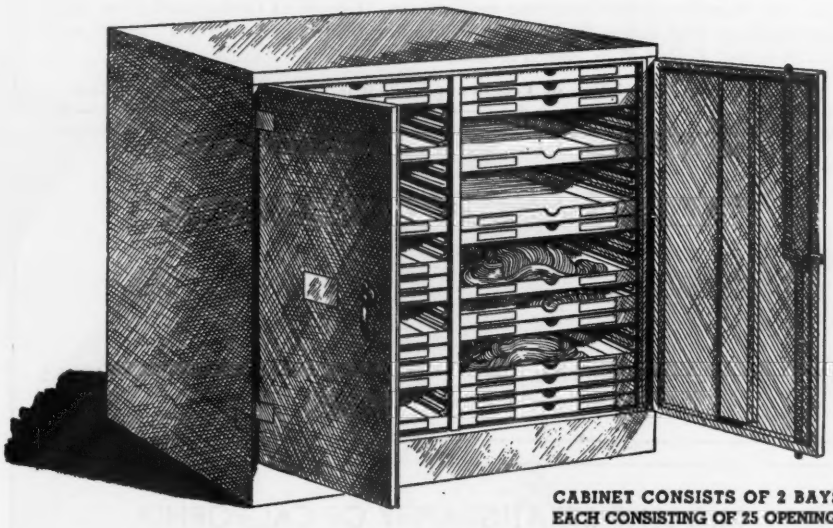

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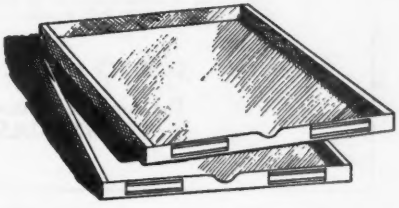

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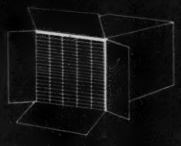

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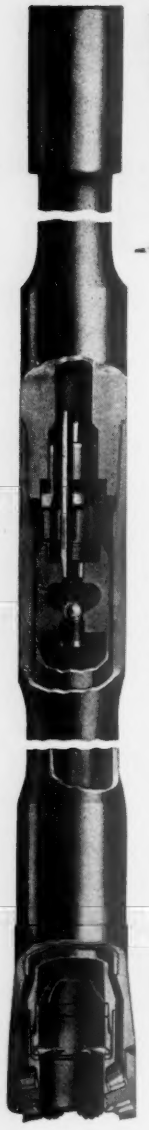

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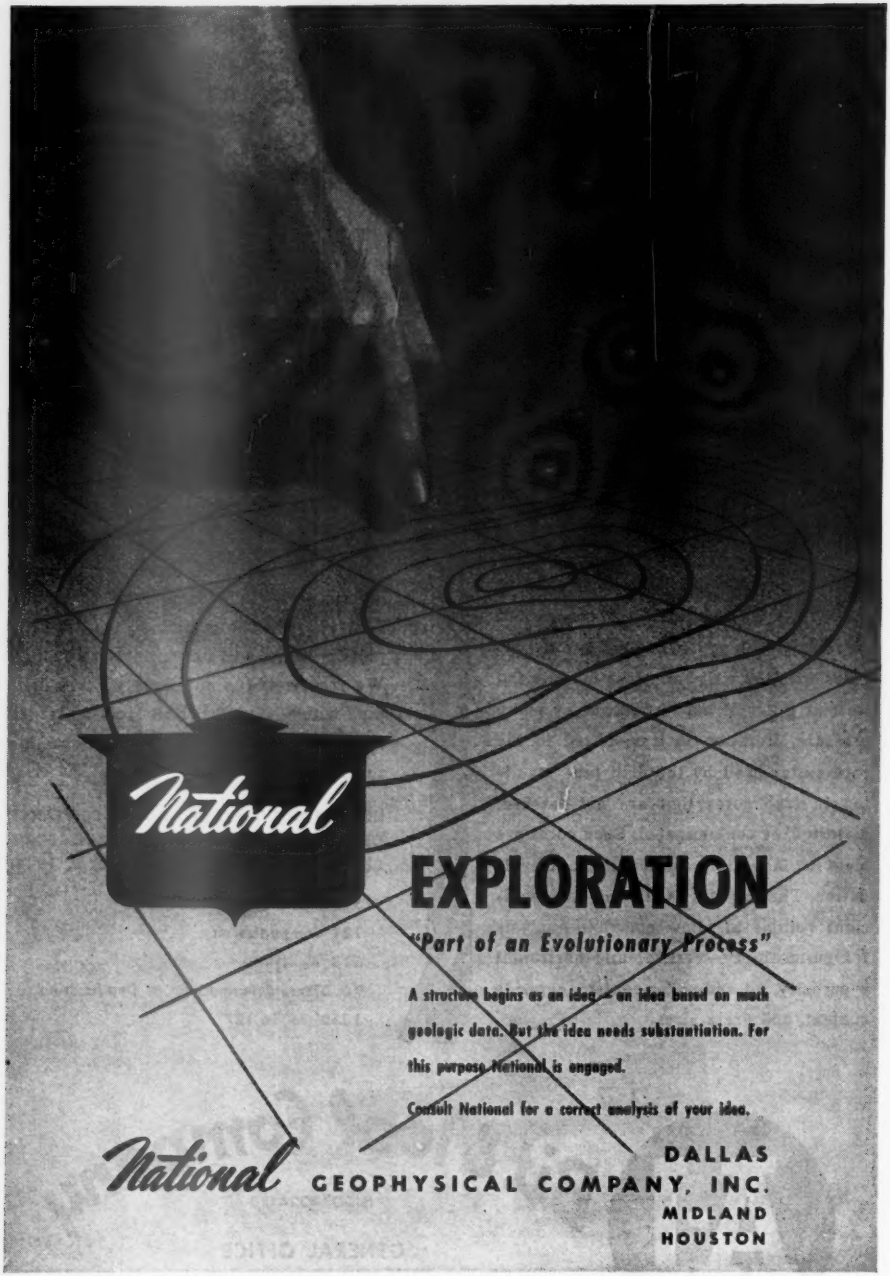
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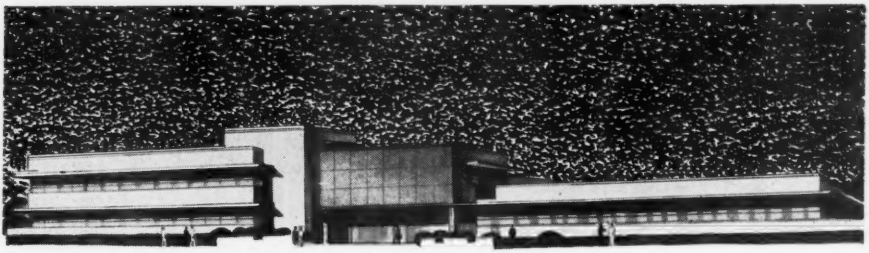

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